Ameren

Ameren Services

December 1, 2015

Ms. Kyra Moore, Director
Air Pollution Control Program
Missouri Department of Natural Resources
P.O. Box 176
Jefferson City, MO 65102

Re: Air Quality Modeling Analysis

Dear Ms. Moore:

On September 3, 2015, Ameren Missouri submitted comments in support of an SO2 classification of "Unclassifiable" for the area around the Labadie Energy Center. As part of those comments, Ameren submitted an AERMOD modeling analysis using both default and beta options. EPA recently held a conference on Air Quality Modeling and public hearing wherein the use of various alternatives such as the use of "low-wind option" as an AERMOD default input. It is critical that the most accurate and appropriate modeling option be used as, depending on the AERMOD options chosen; the Franklin County area either demonstrates attainment or nonattainment with the SO2 standard. Ameren Missouri has installed ambient SO2 and meteorological monitoring sites in areas demonstrated, based on AERMOD modeling recommended by the Air Pollution Control Program, to be representative of areas of higher SO2 concentrations. These sites have been operational since April of 2015 and to date measured air quality data reflects compliance with the SO2 ambient standard.

Attached is a demonstration illustrating that the use of the AERMOD as proposed as default options at EPA's 11th conference on Air Quality Modeling are appropriate for this area.

Please contact me at your convenience if you have questions or if you need additional information.

Sincerely,

Steven C. Whitworth
Senior Director, Environmental Policy and Analysis

Attachments

Cc: Michael Jay – USEPA Region 7

Evaluations and Regulatory Acceptance of AERMOD Low Wind Speed Options

Robert Paine, AECOM

November 12, 2015

1. Introduction and Background

EPA is proposing[1] to adopt as default options the low wind speed improvements to AERMET ("ADJ_U*" option) and AERMOD ("LOWWIND3" option). As discussed below, these options improve model accuracy and are based on peer-reviewed studies as well as evaluations by EPA and other investigators.

In 2010, the results of an evaluation of low wind speed databases for short-range modeling applications were provided to EPA by AECOM in a study funded by the American Petroleum Institute (API) and the Utility Air Regulatory Group (UARG). The study was conducted because some of the most restrictive dispersion conditions and the highest model predictions occur under low wind speed conditions, but there had been limited model evaluation for these conditions. The results of the evaluation indicated that in low wind conditions, the friction velocity formulation in AERMET results in under-predictions of this important planetary boundary layer parameter. There were several modeling implications of this under-prediction: mechanical mixing heights that were very low (less than 10 meters), very low effective dilution wind speeds, and very low turbulence in stable conditions. In addition, the evaluation study concluded that the minimum lateral turbulence (as implemented in AERMOD through sigma-v) was too low by at least a factor of 2.

In late 2012, following further review of these issues at the 10th EPA Modeling Conference, EPA made revisions to the AERMOD modeling system to correct the model deficiencies in this area. This culminated in EPA releasing AERMET and AERMOD Version 12345, which included "beta" options in AERMET for a revised u* formulation under stable conditions and two different low wind speed options in AERMOD. After its release, a bug was found with the "beta" options. The EPA subsequently released AERMET and AERMOD Version 13350 with corrections to this issue and other updates.

Among the changes incorporated into AERMOD 13350 are updates to the AERMET meteorological processor, described in the model change bulletin at

[1] 80 FR 45340, July 29, 2015 Federal Register.

http://www.epa.gov/ttn/scram/7thconf/aermod/aermet_mcb4.txt. One of the changes provides a "bug fix" to the friction velocity (u*) computation, as stated in the bulletin:
"Modified subroutine UCALST to incorporate AECOM's recommended corrections to theta-star under the ADJ_U Beta option, based on Qian and Venkatram, that was incorporated in version 12345 of AERMET".*

EPA presented further (updated) information[2] in support of the low wind options at the 11th Modeling Conference on August 12, 2015. In their verbal comments[3] at the conference, EPA noted for low wind options that much supporting information was provided, and that "We hope to be moving forward with the Clearinghouse action. We're hoping through that action lowering the bar."

2. Additional Evaluations for Tall Stacks

In addition to the evaluation information provided by EPA, AECOM has conducted additional testing of the low wind options (ADJ_U* in AERMOD and LOWWIND3 in AERMOD) for tall stack databases. Based upon these tests, we provide in **Attachment A** a general discussion of elements that are part of a request for the use of an alternative modeling approach.

The results of the testing have been published as a peer-reviewed paper in the November 2015 issue of the Journal of the Air & Waste Management Association; this paper is provided in **Attachment B**. The results of supplemental testing of the proposed options in AERMET and AERMOD version 15181 (ADJ_U* and LOWWIND3) with these two tall-stack databases are presented in **Attachment C**. Modeling files associated with these tests have previously been submitted to George Bridgers of EPA's Office of Air Quality Planning and Standards to accompany comments to the EPA docket for the proposed changes to Appendix W. These comments were made on behalf of two organizations: the American Petroleum Institute and the American Iron and Steel Association.

Attachment A references a modeling report conducted for the Labadie Energy Center that describes the low wind options and other modeling approaches used by AECOM. This report is available as **Attachment D**.

3. Other Applications of the Low Wind Options

Other investigators have applied the low wind options and have submitted their modeling files to reviewing agencies. These submittals have resulted in approvals or pending approvals for the use of these options.

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[2] http://www3.epa.gov/ttn/scram/11thmodconf/presentations/1-5_Proposed_Updates_AERMOD_System.pdf.

[3] http://www3.epa.gov/ttn/scram/11thmodconf/presentations/2015_Eleventh_Modeling_Conference-Transcripts_08-12-2015.pdf, page 65.

Eastman Chemical Company, Tennessee

This modeling application was conducted to resolve an SO_2 nonattainment area (for the 1-hour NAAQS). A modeling evaluation study compared the AERMOD modeling approach to AERMOD using, among other refinements, the ADJ_U* option in AERMET and a LOWWIND2 option with a minimum sigma-v of 0.4 m/s (similar to the newly proposed LOWWIND3 option). EPA Region 4 and the Tennessee Department of Environmental Conservation have accepted this modeling approach. The modeling study involved 4 monitors operated for a full year, along with site-specific meteorological data. **Attachment E** is a report that describes the evaluation study and the use of the low wind options (for AERMOD version 14134). **Attachment F** is a letter from EPA Region 4 that approves the use of these low wind options.

Gavin Power Plant, Ohio

This modeling application was conducted for two adjacent large coal-fired power plants in southern Ohio that were identified as priority facilities by the Consent Decree between the EPA and Sierra Club and the Natural Resources Defense Council. This agreement identified areas that contain stationary sources that emitted more than 16,000 tons of SO_2 or emitted more than 2,600 tons of SO_2 and had an emission rate of at least 0.45 lbs SO_2/MMBtu in 2012. 2012. The EPA identified two facilities in Ohio as meeting one or more of these criteria: the General James M. Gavin Plant and the W.H. Zimmer Generating Station.

Ohio EPA conducted a performance evaluation[4] of the ADJ_U* and the LOWWIND3 options for a monitor in the vicinity of the Gavin plant. Ohio EPA's model performance evaluation demonstrated that AERMOD performance with respect to monitored values in the vicinity of the Gavin plant improves with the ADJ_U* and LOWWIND3 options enabled. These options also resulted in overestimations of the monitored values, indicating that the low wind options will still provide conservative estimates of SO_2 concentrations. Therefore, Ohio EPA relied upon the use of these options in their submittal[5] to EPA Region 5.

Kentucky has recommended[6] an attainment status for the Cooper Station, based upon recent modeling[7] using the ADJ_U* option. The justification for use of this option is similar to that noted below for the EPA Region 10 approval in Alaska. Basically, the low wind options have been available for public review since late 2012, and there are peer-reviewed papers to support their use for tall-stack releases in addition to low-level releases.

4. Other Regulatory Approvals

There has been at least one additional regulatory approval of the ADJ_U* option, which is described below.

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[4] Available at http://epa.ohio.gov/portals/27/SIP/SO2/C1-Gavin.pdf.

[5] http://epa.ohio.gov/portals/27/SIP/SO2/GavinKyg_Desig_Draft.pdf.

[6] http://www3.epa.gov/so2designations/round2/R4KYRec.pdf.

[7] http://www3.epa.gov/so2designations/round2/R4KYRecAtt2CooperStationModeling.pdf.

EPA Region 10 Approval

For general modeling applications in the state of Alaska, and for the Donlin Gold Limited Liability Company (DGLLC) mine construction and operation project in particular, EPA Region 10 has approved the use of the ADJ_U* option as an alternative model (see **Attachment G**). This justification references the EPA presentations[2] made at the 11th modeling conference as well as in previous presentations[8].

5. Conclusions

This document provides justification for EPA approval of the ADJ_U* and LOWWIND3 improvements to the AERMOD modeling system that EPA itself has proposed for adoption as default options in AERMOD. In addition to the EPA evaluations, additional evaluations have been conducted:

- A peer-reviewed paper (Paine et al., 2015) and follow-up evaluations with the proposed options indicates improved performance by AERMOD for tall-stack sources, while retaining a modest overprediction tendency.
- A robust evaluation study by Eastman Chemical in Tennessee indicated superior performance with the low wind options, and EPA Region 4 approved these options.
- An evaluation study in Ohio had a similar outcome for the proposed low wind options.

EPA Region 10 has also approved the use of the ADJ_U* option for a project in Alaska.

In light of the evaluations and other approvals for these options, it is clear that these proposed options are appropriate and should be approved for general use in Missouri.

[8] http: //www.cleanairinfo.com/regionalstatelocalmodelingworkshop/archive/2013/Files/Presentations/Tuesday/104-Brode_AERMOD_System_Update_RSL-Dallas_04-23-2013.pdf.

Attachment A

Alternative Model Justification for Low Wind Speed Beta Options: AERMET and AERMOD

Alternative Model Justification for Low Wind Speed Beta Options:

AERMET and AERMOD

Appendix W, Section 3.2.2 provides an approach for approval of an alternative model to determine whether it is more appropriate for this modeling application. The principle sources involve tall stack buoyant releases.

EPA indicates that for this purpose, an alternative refined model may be used provided that:

1. The model has received a scientific peer review;
2. The model can be demonstrated to be applicable to the problem on a theoretical basis;
3. The data bases which are necessary to perform the analysis are available and adequate;
4. Appropriate performance evaluations of the model have shown that the model is not biased toward underestimates; and
5. A protocol on methods and procedures to be followed has been established.

These five points are discussed below.

The model selected for this modeling application is the EPA-proposed updates to the AERMOD modeling system version 15181, including the AERMET ADJ_U* option, combined with the AERMOD LOWWIND3 option. EPA has indicated support for these changes in the Appendix W proposal and in the Roger Brode presentation made at the 11th Modeling Conference on August 12, 2015 (see presentation at http://www.epa.gov/ttn/scram/11thmodconf/presentations/1-5_Proposed_Updates_AERMOD_System.pdf).

1. The model has received a scientific peer review

The AERMET changes reference a Boundary-Layer Meteorology peer-reviewed paper[1] that is the source of the AERMET formulation for changes in the friction velocity computation for low wind speeds. The combination of the AERMET changes and the AERMOD changes (version 14134 LOWWIND2, similar to version 15181 LOWWIND3) has been evaluated and the study[2] has been published in the November, 2015 issue of the Journal of the Air & Waste Management Association (JAWMA). The manuscript associated with the JAWMA article is provided in Attachment B. A supplemental evaluation exercise with AERMET/AERMOD version 15181 is provided in Attachment C that shows consistent evaluation results (with a slight improvement) for the proposed AERMOD modeling application.

[1] Qian, W., and A. Venkatram, 2011. Performance of Steady-State Dispersion Models Under Low Wind-Speed Conditions. *Boundary-Layer Meteorology,* 138:475–491.

[2] Paine, R., O. Samani, M. Kaplan, E. Knipping and N. Kumar, 2015. Evaluation of low wind modeling approaches for two tall-stack databases, *Journal of the Air & Waste Management Association*, 65:11, 1341-1353, DOI: 10.1080/10962247.2015.1085924.

2. The model can be demonstrated to be applicable to the problem on a theoretical basis.

There is no theoretical limitation to the application of the AERMET and AERMOD low wind changes – they are generally applicable. The current default algorithm in AERMET has been demonstrated to be faulty and needs to be replaced by the ADJ_U* approach. The improvements due to the LOWWIND3 algorithm are demonstrated with the low wind model evaluations reported by the presentations[3] at the 11th EPA modeling conference and in Attachment C.

3. The data bases which are necessary to perform the analysis are available and adequate.

Routine meteorological databases that are already available are sufficient for exercising this low wind options. There are no special database requirements for the use of these options.

4. Appropriate performance evaluations of the model have shown that the model is not biased toward underestimates.

The studies cited above by EPA and AECOM provide this demonstration.

5. A protocol on methods and procedures to be followed has been established.

The AECOM modeling documentation associated with the case-specific application (characterizing the SO_2 concentrations near the Labadie Energy Center) for this procedure is provided in Attachment D. Modeling files consistent with this document were separately provided to the MDNR.

Compared to modeling previously conducted by the Missouri DNR, the modeling documented in Attachment D differed in the following ways, as noted[4] by the MDNR in their "Area Boundary Recommendations for the 2010 1-hour Sulfur Dioxide Standard – July 2016 Designations".

- The most recent version of AERMOD, version 15181 (released by EPA in July 2015), was used. This version contains certain bug fixes and enhancements relative to AERMOD version 14134, which was used by the MDNR.
- The AECOM analysis utilized the low wind options (ADJ_U* and LOWWIND3) that are proposed[5] by EPA for adoption as preferred AERMOD options.
- AECOM merged the emission releases from units 3 and 4 at Labadie because they are flues in a common stack, consistent with the guidance provided by EPA Model Clearinghouse Memo 91-II-01. MDNR modeled these adjacent flues as individual release points.
- AECOM also used a more representative (rural) site to characterize the unmodeled background concentrations in the region.
- AECOM obtained hourly stack release parameters (temperature and flow rate) from Ameren that were not previously available to the MDNR.

Each of these differences can be considered as a refinement to the approach used by the MDNR.

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[3] http://www.epa.gov/ttn/scram/11thmodconf/presentations/1-5_Proposed_Updates_AERMOD_System.pdf and http://www.epa.gov/ttn/scram/11thmodconf/presentations/2-3_Low_Wind_Speed_Evaluation_Study.pdf.

[4] Available at http://dnr.mo.gov/env/apcp/docs/adoption-september242015.pdf.

[5] 80 FR 45340. July 29, 2015.

Attachment B

“Evaluation of low wind modeling approaches for two tall-stack databases”

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Evaluation of low wind modeling approaches for two tall-stack databases

Robert Paine, Olga Samani, Mary Kaplan, Eladio Knipping & Naresh Kumar

TECHNICAL PAPER

Evaluation of low wind modeling approaches for two tall-stack databases

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The performance of the AERMOD air dispersion model under low wind speed conditions, especially for applications with only one level of meteorological data and no direct turbulence measurements or vertical temperature gradient observations, is the focus of this study. The analysis documented in this paper addresses evaluations for low wind conditions involving tall stack releases for which multiple years of concurrent emissions, meteorological data, and monitoring data are available. AERMOD was tested on two field-study databases involving several SO_2 monitors and hourly emissions data that had sub-hourly meteorological data (e.g., 10-min averages) available using several technical options: default mode, with various low wind speed beta options, and using the available sub-hourly meteorological data. These field study databases included (1) Mercer County, a North Dakota database featuring five SO_2 monitors within 10 km of the Dakota Gasification Company's plant and the Antelope Valley Station power plant in an area of both flat and elevated terrain, and (2) a flat-terrain setting database with four SO_2 monitors within 6 km of the Gibson Generating Station in southwest Indiana. Both sites featured regionally representative 10-m meteorological databases, with no significant terrain obstacles between the meteorological site and the emission sources. The low wind beta options show improvement in model performance helping to reduce some of the overprediction biases currently present in AERMOD when run with regulatory default options. The overall findings with the low wind speed testing on these tall stack field-study databases indicate that AERMOD low wind speed options have a minor effect for flat terrain locations, but can have a significant effect for elevated terrain locations. The performance of AERMOD using low wind speed options leads to improved consistency of meteorological conditions associated with the highest observed and predicted concentration events. The available sub-hourly modeling results using the Sub-Hourly AERMOD Run Procedure (SHARP) are relatively unbiased and show that this alternative approach should be seriously considered to address situations dominated by low-wind meander conditions.

Implications: AERMOD was evaluated with two tall stack databases (in North Dakota and Indiana) in areas of both flat and elevated terrain. AERMOD cases included the regulatory default mode, low wind speed beta options, and use of the Sub-Hourly AERMOD Run Procedure (SHARP). The low wind beta options show improvement in model performance (especially in higher terrain areas), helping to reduce some of the overprediction biases currently present in regulatory default AERMOD. The SHARP results are relatively unbiased and show that this approach should be seriously considered to address situations dominated by low-wind meander conditions.

Introduction

During low wind speed (LWS) conditions, the dispersion of pollutants is limited by diminished fresh air dilution. Both monitoring observations and dispersion modeling results of this study indicate that high ground-level concentrations can occur in these conditions. Wind speeds less than 2 m/sec are generally considered to be "low," with steady-state modeling assumptions compromised at these low speeds (Pasquill et al., 1983). Pasquill and Van der Hoven (1976) recognized that for such low wind speeds, a plume is unlikely to have any definable travel. Wilson et al. (1976) considered this wind speed (2 m/sec) as the upper limit for conducting tracer experiments in low wind speed conditions.

Anfossi et al. (2005) noted that in LWS conditions, dispersion is characterized by meandering horizontal wind oscillations. They reported that as the wind speed decreases, the standard deviation of the wind direction increases, making it more difficult to define a mean plume direction. Sagendorf and Dickson (1974) and Wilson et al. (1976) found that under LWS conditions, horizontal diffusion was enhanced because of this meander and the resulting ground-level concentrations could be much lower than that predicted by steady-state Gaussian plume models that did not account for the meander effect.

A parameter that is used as part of the computation of the horizontal plume spreading in the U.S. Environmental Protection Agency (EPA) preferred model, AERMOD (Cimorelli et al., 2005), is the standard deviation of the crosswind component, σ_v, which can be parameterized as being proportional to the friction velocity, u_* (Smedman, 1988; Mahrt, 1998). These investigators

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Color versions of one or more of the figures in the article can be found online at www.tandfonline.com/uawm.

found that there was an elevated minimum value of σ_v that was attributed to meandering. While at higher wind speeds small-scale turbulence is the main source of variance, lateral meandering motions appear to exist in all conditions. Hanna (1990) found that σ_v maintains a minimum value of about 0.5 m/sec even as the wind speed approaches zero. Chowdhury et al. (2014) noted that a minimum σ_v of 0.5 m/s is a part of the formulation for the SCICHEM model. Anfossi (2005) noted that meandering exists under all meteorological conditions regardless of the stability or wind speed, and this phenomenon sets a lower limit for the horizontal wind component variances as noted by Hanna (1990) over all types of terrain.

An alternative method to address wind meander was attempted by Sagendorf and Dickson (1974), who used a Gaussian model, but divided each computation period into sub-hourly (2-min) time intervals and then combined the results to determine the total hourly concentration. This approach directly addresses the wind meander during the course of an hour by using the sub-hourly wind direction for each period modeled. As we discuss later, this approach has some appeal because it attempts to use direct wind measurements to account for sub-hourly wind meander. However, the sub-hourly time interval must not be so small as to distort the basis of the horizontal plume dispersion formulation in the dispersion model (e.g., AERMOD). Since the horizontal dispersion shape function for stable conditions in AERMOD is formulated with parameterizations derived from the 10-min release and sampling times of the Prairie Grass experiment (Barad, 1958), it is appropriate to consider a minimum sub-hourly duration of 10 minutes for such modeling using AERMOD. The Prairie Grass formulation that is part of AERMOD may also result in an underestimate of the lateral plume spread shape function in some cases, as reported by Irwin (2014) for Kincaid SF_6 releases. From analyses of hourly samples of SF_6 taken at Kincaid (a tall stack source), Irwin determined that the lateral dispersion simulated by AERMOD could underestimate the lateral dispersion (by 60%) for near-stable conditions (conditions for which the lateral dispersion formulation that was fitted to the Project Prairie Grass data could affect results).

It is clear from the preceding discussion that the simulation of pollutant dispersion in LWS conditions is challenging. In the United States, the use of steady-state plume models before the introduction of AERMOD in 2005 was done with the following rule implemented by EPA: "When used in steady-state Gaussian plume models, measured site-specific wind speeds of less than 1 m/sec but higher than the response threshold of the instrument should be input as 1 m/sec" (EPA, 2004).

With EPA's implementation of a new model, AERMOD, in 2005 (EPA, 2005), input wind speeds lower than 1 m/sec were allowed due to the use of a meander algorithm that was designed to account for the LWS effects. As noted in the AERMOD formulation document (EPA, 2004), "AERMOD accounts for meander by interpolating between two concentration limits: the coherent plume limit (which assumes that the wind direction is distributed about a well-defined mean direction with variations due solely to lateral turbulence) and the random plume limit (which assumes an equal probability of any wind direction)."

A key aspect of this interpolation is the assignment of a time scale (= 24 hr) at which mean wind information at the source is no longer correlated with the location of plume material at a downwind receptor (EPA, 2004). The assumption of a full diurnal cycle relating to this time scale tends to minimize the weighting of the random plume component relative to the coherent plume component for 1-hr time travel. The resulting weighting preference for the coherent plume can lead to a heavy reliance on the coherent plume, ineffective consideration of plume meander, and a total concentration overprediction.

For conditions in which the plume is emitted aloft into a stable layer or in areas of inhomogeneous terrain, it would be expected that the decoupling of the stable boundary layer relative to the surface layer could significantly shorten this time scale. These effects are discussed by Brett and Tuller (1991), where they note that lower wind autocorrelations occur in areas with a variety of roughness and terrain effects. Perez et al. (2004) noted that the autocorrelation is reduced in areas with terrain and in any terrain setting with increasing height in stable conditions when decoupling of vertical motions would result in a "loss of memory" of surface conditions. Therefore, the study reported in this paper has reviewed the treatment of AERMOD in low wind conditions for field data involving terrain effects in stable conditions, as well as for flat terrain conditions, for which convective (daytime) conditions are typically associated with peak modeled predictions.

The computation of the AERMOD coherent plume dispersion and the relative weighting of the coherent and random plumes in stable conditions are strongly related to the magnitude of σ_v, which is directly proportional to the magnitude of the friction velocity. Therefore, the formulation of the friction velocity calculation and the specification of a minimum σ_v value are also considered in this paper. The friction velocity also affects the internally calculated vertical temperature gradient, which affects plume rise and plume–terrain interactions, which are especially important in elevated terrain situations.

Qian and Venkatram (2011) discuss the challenges of LWS conditions in which the time scale of wind meandering is large and the horizontal concentration distribution can be non-Gaussian. It is also quite possible that wind instrumentation cannot adequately detect the turbulence levels that would be useful for modeling dispersion. They also noted that an analysis of data from the Cardington tower indicates that Monin–Obukhov similarity theory underestimates the surface friction velocity at low wind speeds. This finding was also noted by Paine et al. (2010) in an independent investigation of Cardington data as well as data from two other research-grade databases. Both Qian and Venkatram and Paine et al. proposed similar adjustments to the calculation of the surface friction velocity by AERMET, the meteorological processor for AERMOD. EPA incorporated the Qian and Venkatram suggested approach as a "beta option" in AERMOD in late 2012 (EPA, 2012). The same version of AERMOD also introduced low wind modeling options affecting the minimum value of σ_v and the weighting of the meander component that were used in the Test Cases 2–4 described in the following.

AERMOD's handling of low wind speed conditions, especially for applications with only one level of meteorological data and no direct turbulence measurements or vertical temperature gradient observations, is the focus of this study. Previous evaluations of AERMOD for low wind speed conditions (e.g., Paine et al., 2010) have emphasized low-level tracer release studies conducted in the 1970s and have utilized results of researchers such as Luhar and Rayner (2009). The focus of the study reported here is a further evaluation of AERMOD, but focusing upon tall-stack field databases. One of these databases was previously evaluated (Kaplan et al., 2012) with AERMOD Version 12345, featuring a database in Mercer County, North Dakota. This database features five SO_2 monitors in the vicinity of the Dakota Gasification Company plant and the Antelope Valley Station power plant in an area of both flat and elevated terrain. In addition to the Mercer County, ND, database, this study considers an additional field database for the Gibson Generating Station tall stack in flat terrain in southwest Indiana.

EPA released AERMOD version 14134 with enhanced low wind model features that can be applied in more than one combination. There is one low wind option (beta u_*) applicable to the meteorological preprocessor, AERMET, affecting the friction velocity calculation, and a variety of options available for the dispersion model, AERMOD, that focus upon the minimum σ_v specification. These beta options have the potential to reduce the overprediction biases currently present in AERMOD when run for neutral to stable conditions with regulatory default options (EPA, 2014a, 2014b). These new low wind options in AERMET and AERMOD currently require additional justification for each application in order to be considered for use in the United States. While EPA has conducted evaluations on low-level, nonbuoyant studies with the AERMET and AERMOD low wind speed beta options, it has not conducted any new evaluations on tall stack releases (U.S. EPA, 2014a, 2014b). One of the purposes of this study was to augment the evaluation experiences for the low wind model approaches for a variety of settings for tall stack releases.

This study also made use of the availability of sub-hourly meteorological observations to evaluate another modeling approach. This approach employs AERMOD with sub-hourly meteorological data and is known as the Sub-Hourly AERMOD Run Procedure or SHARP (Electric Power Research Institute [EPRI], 2013). Like the procedure developed by Sagendorf and Dickson as described earlier, SHARP merely subdivides each hour's meteorology (e.g., into six 10-min periods) and AERMOD is run multiple times with the meteorological input data (e.g., minutes 1–10, 11–20, etc.) treated as "hourly" averages for each run. Then the results of these runs are combined (averaged). In our SHARP runs, we did not employ any observed turbulence data as input. This alternative modeling approach (our Test Case 5 as discussed later) has been compared to the standard hourly AERMOD modeling approach for default and low wind modeling options (Test Cases 1–4 described later, using hourly averaged meteorological data) to determine whether it should be further considered as a viable technique. This study provides a discussion of the various low wind speed modeling options and the field study databases that were tested, as well as the modeling results.

Modeling Options and Databases for Testing

Five AERMET/AERMOD model configurations were tested for the two field study databases, as listed in the following. All model applications used one wind level, a minimum wind speed of 0.5 m/sec, and also used hourly average meteorological data with the exception of SHARP applications. As already noted, Test Cases 1–4 used options available in the current AERMOD code. The selections for Test Cases 1–4 exercised these low wind speed options over a range of reasonable choices that extended from no low wind enhancements to a full treatment that incorporates the Qian and Venkatram (2011) u_* recommendations as well as the Hanna (1990) and Chowdhury (2014) minimum σ_v recommendations (0.5 m/sec). Test Case 5 used sub-hourly meteorological data processed with AERMET using the beta u_* option for SHARP applications. We discuss later in this document our recommendations for SHARP modeling without the AERMOD meander component included.

Test Case 1: AERMET and AERMOD in default mode.

Test Case 2: Low wind beta option for AERMET and default options for AERMOD (minimum σ_v value of 0.2 m/sec).

Test Case 3: Low wind beta option for AERMET and the LOWWIND2 option for AERMOD (minimum σ_v value of 0.3 m/sec).

Test Case 4: Low wind beta option for AERMET and the LOWWIND2 option for AERMOD (minimum σ_v value of 0.5 m/sec).

Test Case 5: Low wind beta option for AERMET and AERMOD run in sub-hourly mode (SHARP) with beta u*option.

The databases that were selected for the low wind model evaluation are listed in Table 1 and described next. They were selected due to the following attributes:

- They feature multiple years of hourly SO_2 monitoring at several sites.
- Emissions are dominated by tall stack sources that are available from continuous emission monitors.
- They include sub-hourly meteorological data so that the SHARP modeling approach could be tested as well.
- There are representative meteorological data from a single-level station typical of (or obtained from) airport-type data.

Mercer County, North Dakota. An available 4-year period of 2007–2010 was used for the Mercer County, ND, database with five SO_2 monitors within 10 km of two nearby emission facilities (Antelope Valley and Dakota Gasification Company), site-specific meteorological data at the DGC#12 site (10-m level data in a low-cut grassy field in the location shown in Figure 1), and hourly emissions data from 15 point sources. The terrain in the area is rolling and features three of the monitors (Beulah, DGC#16, and especially DGC#17) being above or close to stack top for some of the nearby emission sources; see Figure 2 for more close-up terrain details. Figure 1 shows a layout of the sources, monitors, and the meteorological station. Tables 2 and 3 provide details about the emission sources and the monitors. Although this modeling application employed sources as far away as 50 km, the proximity of the monitors to the two nearby emission facilities meant that emissions from those facilities dominated the impacts. However, to avoid criticism from reviewers that other regional sources that

Table 1. Databases selected for the model evaluation.

	Mercer County, North Dakota	Gibson Generating Station, Indiana
Number of emission sources modeled	15	5
Number of SO_2 monitors	5 (one above stack top for several sources)	4 (all below stack top)
Type of terrain	Rolling	Flat
Meteorological years and data source	2007–2010 Local 10-m tower data	2008–2010 Evansville airport
Meteorological data time step	Hourly and sub-hourly	Hourly and sub-hourly
Emissions and exhaust data	Actual hourly variable emissions and velocity, fixed temperature	Actual hourly variable emissions and velocity, fixed temperature

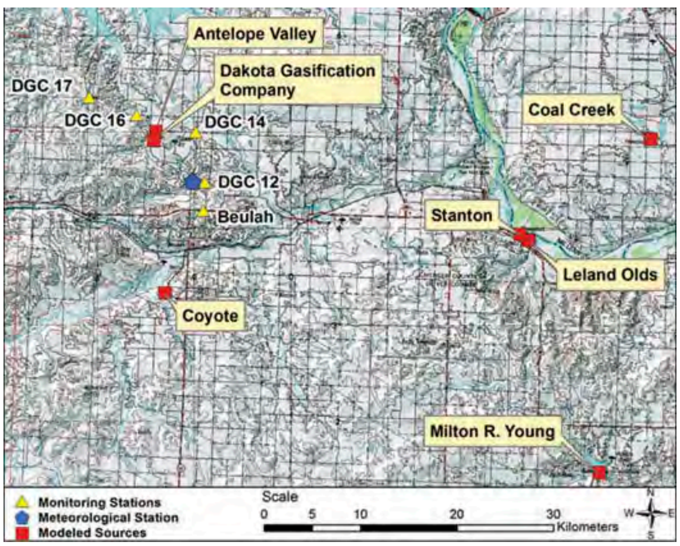

Figure 1. Map of North Dakota model evaluation layout.

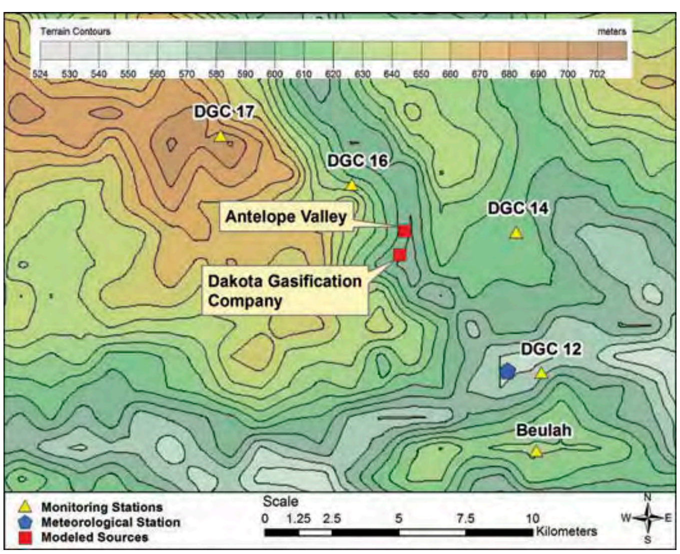

Figure 2. Terrain around the North Dakota monitors.

should have been modeled were omitted, other regional lignite-fired power plants were included in the modeling.

Gibson Generating Station, Indiana. An available 3-year period of 2008–2010 was used for the Gibson Generating Station in southwest Indiana with four SO_2 monitors within 6 km of the plant, airport hourly meteorological data (from Evansville, IN, 1-min data, located about 40 km SSE of the plant), and hourly emissions data from one electrical generating station (Gibson). The terrain in the area is quite flat and the stacks are tall. Figure 3 depicts the locations of the emission source and the four SO_2 monitors. Although the plant had an on-site meteorological tower, EPA (2013a) noted that the tower's location next to a large lake resulted in nonrepresentative boundary-layer conditions for the area, and that the use of airport data would be preferred. Tables 2 and 3 provide details about the emission sources and the monitors. Due to the fact that there are no major SO_2 sources within at least 30 km of Gibson, we modeled emissions from only that plant.

Meteorological Data Processing

For the North Dakota and Gibson database evaluations, the hourly surface meteorological data were processed with AERMET, the meteorological preprocessor for AERMOD. The boundary layer parameters were developed according to the guidance provided by EPA in the current AERMOD Implementation Guide (EPA, 2009). For the first modeling evaluation option, Test Case 1, AERMET was run using the default options. For the other four model evaluation options, Test Cases 2 to 5, AERMET was run with the beta u_* low wind speed option.

North Dakota meteorological processing

Four years (2007–2010) of the 10-m meteorological data collected at the DGC#12 monitoring station (located about 7 km SSE of the central emission sources) were processed with AERMET. The data measured at this monitoring station were wind direction, wind speed, and temperature. Hourly cloud

Table 2. Source information.

Database	Source ID	UTM X (m)	UTM Y (m)	Base elevation (m)	Stack height (m)	Exit temperature (K)	Stack diameter (m)
ND	Antelope Valley	285920	5250189	588.3	182.9	Vary	7.0
ND	Antelope Valley	285924	5250293	588.3	182.9	Vary	7.0
ND	Leland Olds	324461	5239045	518.3	106.7	Vary	5.3
ND	Leland Olds	324557	5238972	518.3	152.4	Vary	6.7
ND	Milton R Young	331870	5214952	597.4	171.9	Vary	6.2
ND	Milton R Young	331833	5214891	600.5	167.6	Vary	9.1
ND	Coyote	286875	5233589	556.9	151.8	Vary	6.4
ND	Stanton	323642	5239607	518.2	77.7	Vary	4.6
ND	Coal Creek	337120	5249480	602.0	201.2	Vary	6.7
ND	Coal Creek	337220	5249490	602.0	201.2	Vary	6.7
ND	Dakota Gasification Company	285552	5249268	588.3	119.8	Vary	7.0
ND	Dakota Gasification Company	285648	5249553	588.3	68.6	Vary	0.5
ND	Dakota Gasification Company	285850	5248600	588.3	76.2	Vary	1.0
ND	Dakota Gasification Company	285653	5249502	588.3	30.5	Vary	0.5
Gibson	Gibson 1	432999	4247189	119.0	189.0	327.2	7.6
Gibson	Gibson 2	432999	4247189	119.0	189.0	327.2	7.6
Gibson	Gibson 3	432923	4247251	118.5	189.0	327.2	7.6
Gibson	Gibson 4	432886	4247340	117.9	152.4	327.2	7.2
Gibson	Gibson 5	432831	4247423	116.3	152.4	327.2	7.2

Notes: SO_2 emission rate and exit velocity vary on hourly basis for each modeled source. Exit temperature varies by hour for the ND sources. UTM zones are 14 for North Dakota and 16 for Gibson.

Table 3. Monitor locations.

Database	Monitor	UTM X (m)	UTM Y (m)	Monitor elevation (m)
ND	DGC#12	291011	5244991	593.2
ND	DGC#14	290063	5250217	604.0
ND	DGC#16	283924	5252004	629.1
ND	DGC#17[a]	279025	5253844	709.8
ND	Beulah	290823	5242062	627.1
Gibson	Mt. Carmel	432424	4250202	119.0
Gibson	East Mt. Carmel	434654	4249666	119.3
Gibson	Shrodt	427175	4247182	138.0
Gibson	Gibson Tower	434792	4246296	119.0

Note: [a]This monitor's elevation is above stack top for several of the ND sources.

cover data from the Dickinson Theodore Roosevelt Regional Airport, North Dakota (KDIK) ASOS station (85 km to the SW), were used in conjunction with the monitoring station data. Upper air data were obtained from the Bismarck Airport, North Dakota (KBIS; about 100 km to the SE), twice-daily soundings.

In addition, the sub-hourly (10-min average) 10-m meteorological data collected at the DGC#12 monitoring station were also processed with AERMET. AERMET was set up to read six 10-min average files with the tower data and output six 10-min average surface and profile files for use in SHARP. SHARP then used the sub-hourly output of AERMET to calculate hourly modeled concentrations, without changing the internal computations of AERMOD. The SHARP user's manual (EPRI, 2013) provides detailed instructions on processing sub-hourly meteorological data and executing SHARP.

Gibson meteorological processing

Three years (2008–2010) of hourly surface data from the Evansville Airport, Indiana (KEVV), ASOS station (about 40 km SSE of Gibson) were used in conjunction with the

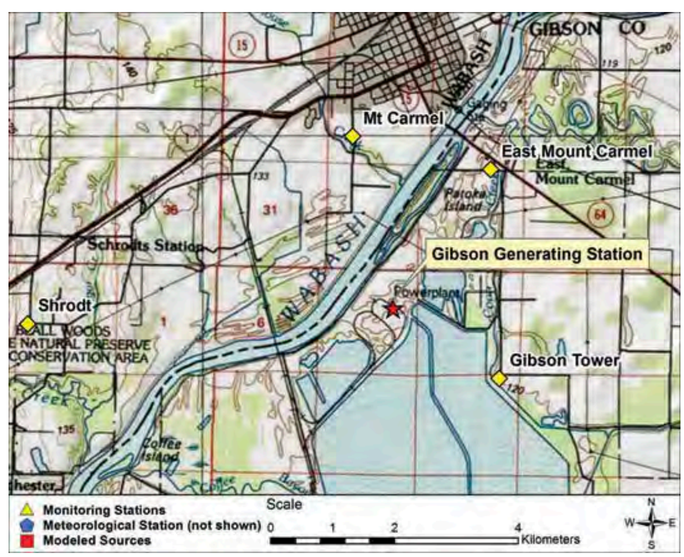

Figure 3. Map of Gibson model evaluation layout.

twice-daily soundings upper air data from the Lincoln Airport, Illinois (KILX, about 240 km NW of Gibson). The 10-min sub-hourly data for SHARP were generated from the 1-min meteorological data collected at Evansville Airport.

Emission Source Characteristics

Table 2 summarizes the stack parameters and locations of the modeled sources for the North Dakota and Gibson databases. Actual hourly emission rates, stack temperatures, and stack gas exit velocities were used for both databases.

Model Runs and Processing

For each evaluation database, the candidate model configurations were run with hourly emission rates provided by the plant operators. In the case of rapidly varying emissions (startup and shutdown), the hourly averages may average intermittent conditions occurring during the course of the hour. Actual stack heights were used, along with building dimensions used as input to the models tested. Receptors were placed only at the location of each monitor to match the number of observed and predicted concentrations.

The monitor (receptor) locations and elevations are listed in Table 3. For the North Dakota database, the DGC#17 monitor is located in the most elevated terrain of all monitors. The monitors for the Gibson database were located at elevations at or near stack base, with stack heights ranging from 152 to 189 m.

Tolerance Range for Modeling Results

One issue to be aware of regarding SO_2 monitored observations is that they can exhibit over- or underprediction tendencies up to 10% and still be acceptable. This is related to the tolerance in the EPA procedures (EPA, 2013b) associated with quality control checks and span checks of ambient measurements. Therefore, even ignoring uncertainties in model input parameters and other contributions (e.g., model science errors and random variations) that can also lead to modeling uncertainties, just the uncertainty in measurements indicates that modeled-to-monitored ratios between 0.9 and 1.1 can be considered “unbiased.” In the discussion that follows, we consider model performance to be “relatively unbiased” if its predicted model to monitor ratio is between 0.75 and 1.25.

Model Evaluation Metrics

The model evaluation employed metrics that address three basic areas, as described next.

The 1-hr SO_2 NAAQS design concentration

An operational metric that is tied to the form of the 1-hour SO_2 National Ambient Air Quality Standards (NAAQS) is the “design concentration” (99th percentile of the peak daily 1-hr maximum values). This tabulated statistic was developed for each modeled case and for each individual monitor for each database evaluated.

Quantile–quantile plots

Operational performance of models for predicting compliance with air quality regulations, especially those involving a peak or near-peak value at some unspecified time and location, can be assessed with quantile–quantile (Q-Q) plots (Chambers et al., 1983), which are widely used in AERMOD evaluations. Q-Q plots are created by independently ranking (from largest to smallest) the predicted and the observed concentrations from a set of predictions initially paired in time and space. A robust model would have all points on the diagonal (45-degree) line. Such plots are useful for answering the question, “Over a period of time evaluated, does the distribution of the model predictions match those of observations?” Therefore, the Q-Q plot instead of the scatterplot is a pragmatic procedure for demonstrating model performance of applied models, and it is widely used by EPA (e.g., Perry et al. 2005). Venkatram et al. (2001) support the use of Q-Q plots for evaluating regulatory models. Several Q-Q plots are included in this paper in the discussion provided in the following.

Meteorological conditions associated with peak observed versus modeled concentrations

Lists of the meteorological conditions and hours/dates of the top several predictions and observations provide an indication as to whether these conditions are consistent between the model and monitoring data. For example, if the peak observed concentrations generally occur during daytime hours, we would expect that a well-performing model would indicate that the peak predictions are during the daytime as well. Another meteorological variable of interest is the wind speed magnitudes associated with observations and predictions. It would be expected, for example, that if the wind speeds associated with peak observations are low, then the modeled peak predicted hours would have the same characteristics. A brief qualitative summary of this analysis is included in this paper, and supplemental files contain the tables of the top 25 (unpaired) predictions and observations for all monitors and cases tested.

North Dakota Database Model Evaluation Procedures and Results

AERMOD was run for five test cases to compute the 1-hr daily maximum 99th percentile averaged over 4 years at the five ambient monitoring locations listed in Table 3. A regional background of 10 $\mu g/m^3$ was added to the AERMOD modeled predictions. The 1-hr 99th percentile background concentration was computed from the 2007–2010 lowest hourly monitored concentration among the five monitors so as to avoid double-counting impacts from sources already being modeled.

The ratios of the modeled (including the background of 10$\mu g/m^3$) to monitored design concentrations are summarized in

Table 4. North Dakota ratio of monitored to modeled design concentrations.

Test case	Monitor	Observed	Predicted	Ratio
Test Case 1	DGC#12	91.52	109.96	1.20
(Default AERMET, Default	DGC#14	95.00	116.84	1.23
AERMOD)	DGC#16	79.58	119.94	1.51
	DGC#17	83.76	184.48	2.20
	Beulah	93.37	119.23	1.28
Test Case 2	DGC#12	91.52	109.96	1.20
(Beta AERMET, Default	DGC#14	95.00	116.84	1.23
AERMOD)	DGC#16	79.58	119.94	1.51
	DGC#17	83.76	127.93	1.53
	Beulah	93.37	119.23	1.28
Test Case 3	DGC#12	91.52	103.14	1.13
(Beta AERMET, AERMOD with	DGC#14	95.00	110.17	1.16
LOWWIND2 σ_v = 0.3 m/sec)	DGC#16	79.58	111.74	1.40
	DGC#17	83.76	108.69	1.30
	Beulah	93.37	106.05	1.14
Test Case 4	DGC#12	91.52	95.86	1.05
(Beta AERMET, AERMOD with	DGC#14	95.00	100.50	1.06
LOWWIND2 σ_v = 0.5 m/sec)	DGC#16	79.58	106.65	1.34
	DGC#17	83.76	101.84	1.22
	Beulah	93.37	92.32	0.99
Test Case 5	DGC#12	91.52	82.18	0.90
(SHARP)	DGC#14	95.00	84.24	0.89
	DGC#16	79.58	95.47	1.20
	DGC#17	83.76	88.60	1.06
	Beulah	93.37	86.98	0.93

Notes: *Design concentration: 99th percentile peak daily 1-hr maximum, averaged over the years modeled and monitored.

Table 4 and graphically plotted in Figure 4 and are generally greater than 1. (Note that the background concentration is a small fraction of the total concentration, as shown in Table 4.) For the monitors in simple terrain (DGC#12, DGC#14, and Beulah), the evaluation results are similar for both the default and beta options and are within 5–30% of the monitored concentrations depending on the model option. The evaluation result for the monitor in the highest terrain (DGC#17) shows that the ratio of modeled to monitored concentration is more than 2, but when this location is modeled with the AERMET and AERMOD low wind beta options, the ratio is significantly better, at less than 1.3. It is noteworthy that the modeling results for inclusion of just the beta u_* option are virtually identical to the default AERMET run for the simple terrain monitors, but the differences are significant for the higher terrain monitor (DGC#17). For all of the monitors, it is evident that further reductions of AERMOD's overpredictions occur as the minimum σ_v in AERMOD is increased from 0.3 to 0.5 m/sec. For a minimum σ_v of 0.5 m/sec at all the monitors, AERMOD is shown to be conservative with respect to the design concentration.

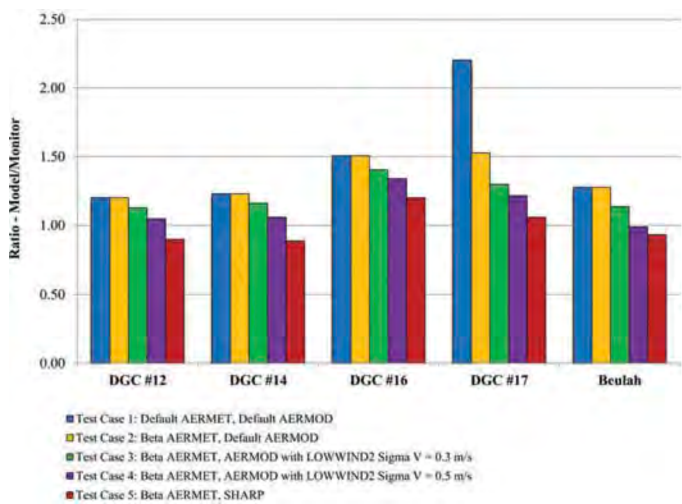

Figure 4. North Dakota ratio of monitored to modeled design concentration values at specific monitors.

The Q-Q plots of the ranked top fifty daily maximum 1-hr SO_2 concentrations for predictions and observations are shown in Figure 5. For the convenience of the reader, a vertical dashed line is included in each Q-Q plot to indicate the observed design concentration. In general, the Q-Q plots indicate the following:

- For all of the monitors, to the left of the design concentration line, the AERMOD hourly runs all show ranked predictions at or higher than observations. To the right of the design concentration line, the ranked modeled values for specific

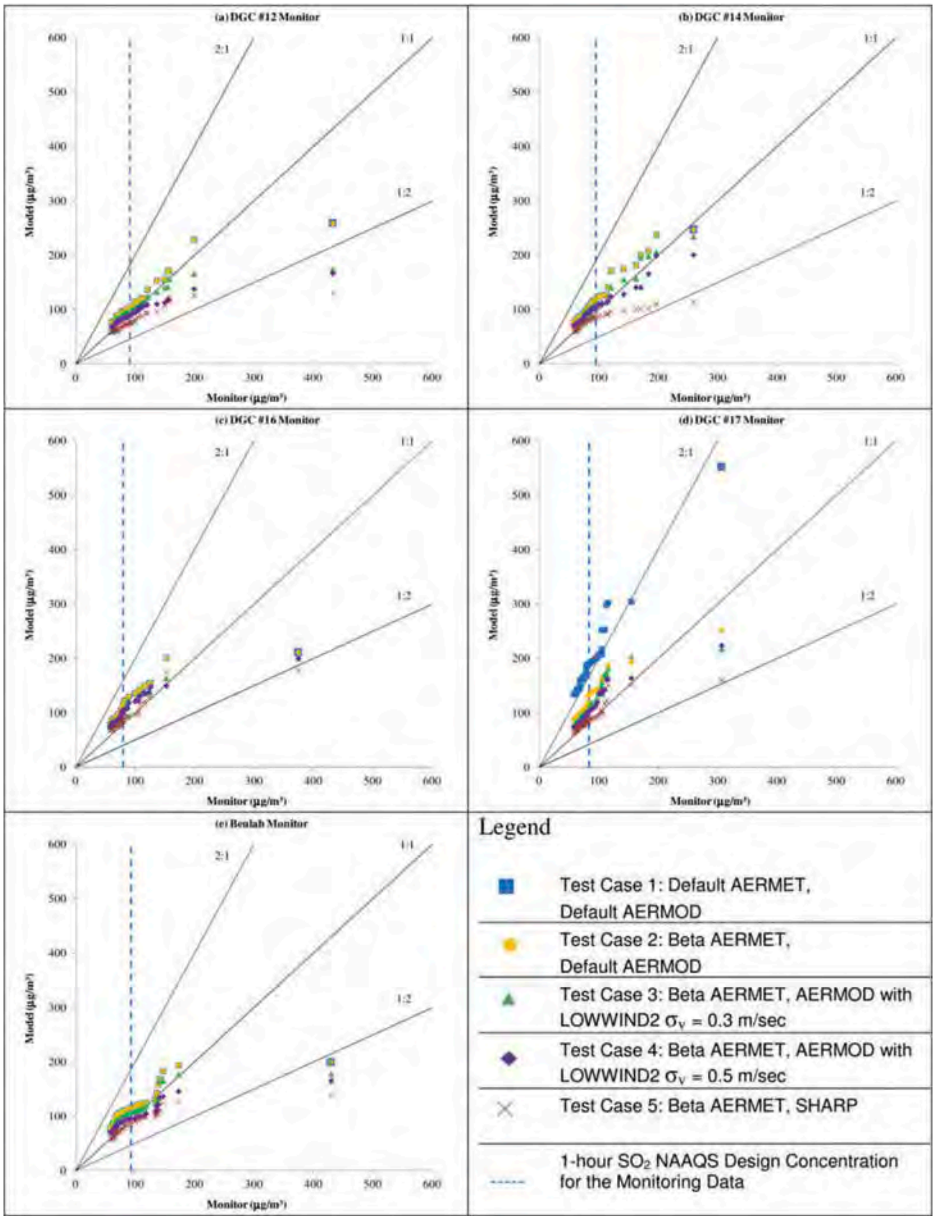

Figure 5. North Dakota Q-Q plots: top 50 daily maximum 1-hr SO_2 concentrations: (a) DGC #12 Monitor. (b) DGC#14 monitor. (c) DGC#16 monitor. (d) DGC#17 monitor. (e) Beulah monitor.

test cases and monitors are lower than the ranked observed levels, and the slope of the line formed by the plotted points is less than the slope of the 1:1 line. For model performance goals that would need to predict well for the peak concentrations (rather than the 99th percentile statistic), this area of the Q-Q plots would be of greater importance.

- The very highest observed value (if indeed valid) is not matched by any of the models for all of the monitors, but since the focus is on the 99th percentile form of the United States ambient standard for SO_2, this area of model performance is not important for this application.
- The ranked SHARP modeling results are lower than all of the hourly AERMOD runs, but at the design concentration level, they are, on average, relatively unbiased over all of the monitors. The AERMOD runs for SHARP included the meander component, which probably contributed to the small underpredictions noted for SHARP. In future modeling, we would advise users of SHARP to employ the AERMOD LOWWIND1 option to disable the meander component.

Gibson Generating Station Database Model Evaluation Procedures and Results

AERMOD was run for five test cases for this database as well in order to compute the 1-hr daily maximum 99th percentile averaged over three years at the four ambient monitoring locations listed in Table 3. A regional background of 18 μg/m^3 was added to the AERMOD modeled predictions. The 1-hr 99th percentile background concentration was computed from the 2008–2010 lowest hourly monitored concentration among the four monitors so as to avoid impacts from sources being modeled.

The ratio of the modeled (including the background of 18 μg/m^3) to monitored concentrations is summarized in Table 5 and graphically plotted in Figure 6 and are generally greater than 1.0. (Note that the background concentration is a small fraction of the total concentration, as shown in Table 5.) Figure 6 shows that AERMOD with hourly averaged meteorological data overpredicts by about 40–50% at Mt. Carmel and Gibson Tower monitors and by about 9–31% at East Mt. Carmel and Shrodt monitors. As expected (due to dominance of impacts with convective conditions), the AERMOD results do not vary much with the various low wind speed options in this flat terrain setting. AERMOD with sub-hourly meteorological data (SHARP) has the best (least biased predicted-to-observed ratio of design concentrations) performance among the five cases modeled. Over the four monitors, the range of predicted-to-observed ratios for SHARP is a narrow one, ranging from a slight underprediction by 2% to an overprediction by 14%.

The Q-Q plots of the ranked top fifty daily maximum 1-hr SO_2 concentrations for predictions and observations are shown in Figure 7. It is clear from these plots that the SHARP results parallel and are closer to the 1:1 line for a larger portion of the concentration range than any other model tested. In general, AERMOD modeling with hourly data exhibits an overprediction tendency at all of the monitors for the peak ranked concentrations at most of the monitors. The AERMOD/SHARP models predicted lower relative to observations at the East Mt. Carmel monitor for the very highest values, but match well for the 99th percentile peak daily 1-hr maximum statistic.

Evaluation Results Discussion

The modeling results for these tall stack releases are sensitive to the source local setting and proximity to complex terrain. In general, for tall stacks in simple terrain, the peak ground-level impacts mostly occur in daytime convective conditions. For settings with a mixture of simple and complex terrain, the peak impacts for the higher terrain are observed to occur during both daytime and nighttime conditions, while AERMOD tends to favor stable conditions only without low wind speed enhancements. Exceptions to this "rule of thumb" can occur for stacks with aerodynamic building downwash effects. In that case, high observed and modeled predictions are likely to occur during high wind events during all times of day.

The significance of the changes in model performance for tall stacks (using a 90th percentile confidence interval) was independently tested for a similar model evaluation conducted for Eastman Chemical Company (Paine et al., 2013; Szembek et al., 2013), using a modification of the Model Evaluation Methodology (MEM) software that computed estimates of the hourly stability class (Strimaitis et al., 1993). That study indicated that relative to a perfect model, a model that

Table 5. Gibson ratio of monitored to modeled design concentrations*.

Test case	Monitor	Observed	Predicted	Ratio
Test Case 1 (Default AERMET, Default AERMOD)	Mt. Carmel	197.25	278.45	1.41
	East Mt. Carmel	206.89	230.74	1.12
	Shrodt	148.16	189.63	1.28
	Gibson Tower	127.12	193.71	1.52
Test Case 2 (Beta AERMET, Default AERMOD)	Mt. Carmel	197.25	287.16	1.46
	East Mt. Carmel	206.89	229.22	1.11
	Shrodt	148.16	189.63	1.28
	Gibson Tower	127.12	193.71	1.52
Test Case 3 (Beta AERMET, AERMOD with LOWWIND2 σ_v = 0.3 m/sec)	Mt. Carmel	197.25	280.32	1.42
	East Mt. Carmel	206.89	224.65	1.09
	Shrodt	148.16	184.82	1.25
	Gibson Tower	127.12	192.22	1.51
Test Case 4 (Beta AERMET, AERMOD with LOWWIND2 σ_v = 0.5 m/sec)	Mt. Carmel	197.25	277.57	1.41
	East Mt. Carmel	206.89	224.65	1.09
	Shrodt	148.16	176.81	1.19
	Gibson Tower	127.12	192.22	1.51
Test Case 5 (SHARP)	Mt. Carmel	197.25	225.05	1.14
	East Mt. Carmel	206.89	202.82	0.98
	Shrodt	148.16	136.41	0.92
	Gibson Tower	127.12	148.64	1.17

Notes: *Design Concentration: 99th percentile peak daily 1-hr maximum, averaged over the years modeled and monitored.

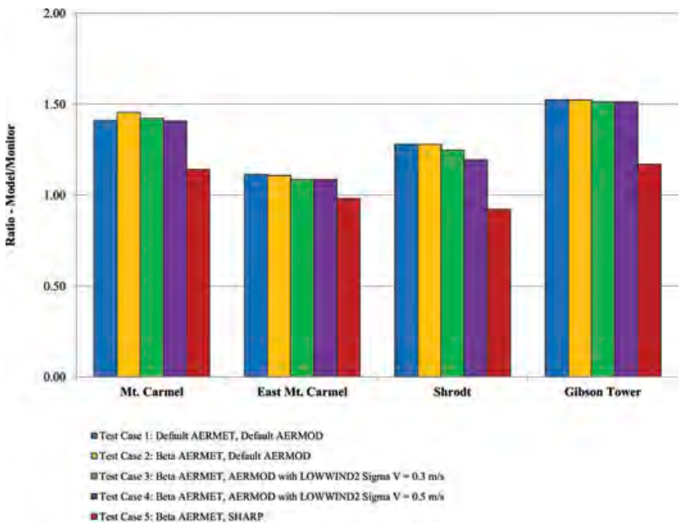

Figure 6. Gibson ratio of monitored to modeled design concentration values at specific monitors.

overpredicted or underpredicted by less than about 50% would likely show a performance level that was not significantly different. For a larger difference in bias, one could expect a statistically significant difference in model performance. This finding has been adopted as an indicator of the significance of different modeling results for this study.

A review of the North Dakota ratios of monitored to modeled values in Figure 4 generally indicates that for DGC#12, DGC#14, and Beulah, the model differences were not significantly different. For DGC#16, it could be concluded that the SHARP results were significantly better than the default AERMOD results, but other AERMOD variations were not significantly better. For the high terrain monitor, DGC#17, it is evident that all of the model options departing from default were significantly better than the default option, especially the SHARP approach.

For the Gibson monitors (see Figure 6), the model variations did not result in significantly different performance except for the Gibson Tower (SHARP vs. the hourly modes of running AERMOD).

General conclusions from the review of meteorological conditions associated with the top observed concentrations at the North Dakota monitors, provided in the supplemental file called "North Dakota Meteorological Conditions Resulting in Top 25 Concentrations," are as follows:

- A few peak observed concentrations occur at night with light winds. The majority of observations for the DGC#12 monitor are mostly daytime conditions with moderate to strong winds.
- Peak observations for the DGC#14 and Beulah monitors are mostly daytime conditions with a large range of wind speeds. Once again, a minority of the peak concentrations occur at night with a large range of wind speeds.

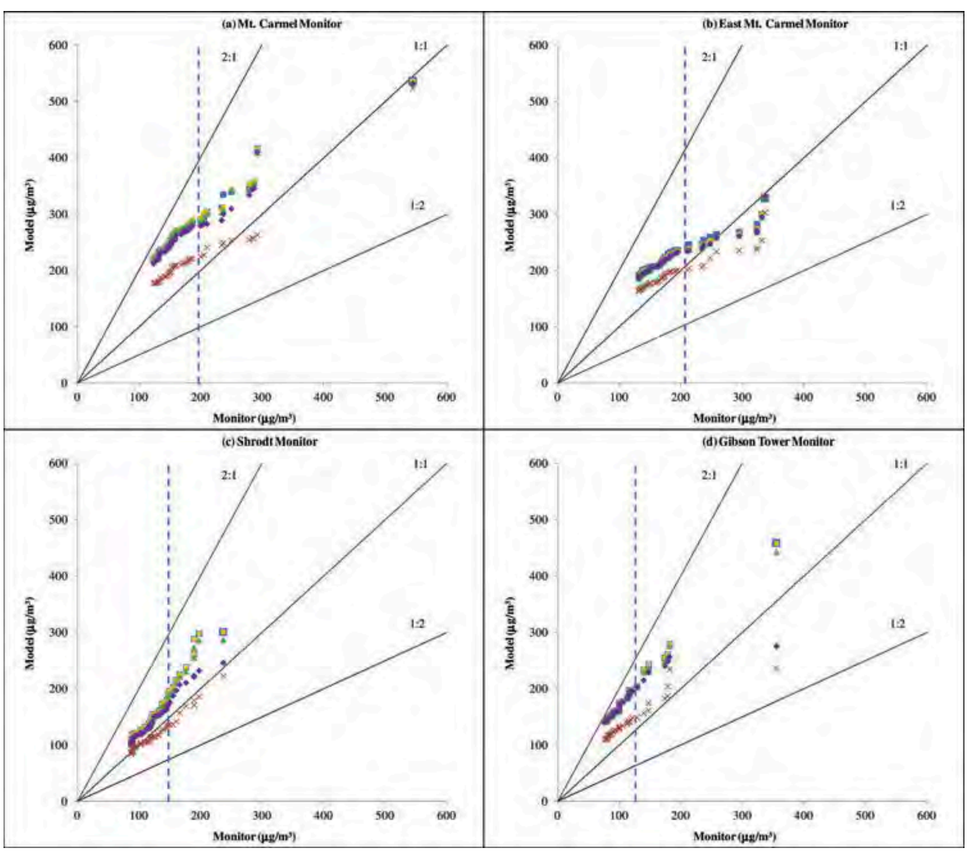

Figure 7. Gibson Q-Q plots: top 50 daily maximum 1-hour SO_2 concentrations. (a) Mt. Carmel monitor. (b) East Mt. Carmel monitor. (c) Shrodt monitor. (d) Gibson tower monitor. For the legend, see Figure 5.

- Peak observed concentrations for the DGC#16 and DGC#17 monitors occur at night with light winds. Majority of observations are mixed between daytime and nighttime conditions with a large range of wind speeds for both. The DGC#17 monitor is located in elevated terrain.

The conclusions from the review of the meteorological conditions associated with peak AERMOD or SHARP predictions are as follows:

- AERMOD hourly peak predictions for the DGC#12 and Beulah monitors are consistently during the daytime with light to moderate wind speeds and limited mixing heights. This is a commonly observed situation that is further discussed later.
- There are similar AERMOD results for DGC#14, except that there are more periods with high winds and higher mixing heights.
- The AERMOD results for DGC#16 still feature mostly daytime hours, but with more high wind conditions.
- The default AERMOD results for DGC#17 are distinctly different from the other monitors, with most hours featuring stable, light winds. There are also a few daytime hours of high predictions with low winds and low mixing heights. This pattern changes substantially with the beta u_* options employed, when the majority of the peak prediction hours are daytime periods with light to moderate wind speeds. This pattern is more consistent with the peak observed concentration conditions.
- The SHARP peak predictions at the North Dakota monitors were also mostly associated with daytime hours with a large range of wind speeds for all of the monitors.

The North Dakota site has some similarities due to a mixture of flat and elevated terrain to the Eastman Chemical Company model evaluation study in Kingsport, TN (this site features three coal-fired boiler houses with tall stacks). In that study (Paine et al. 2013; Szembek et al., 2013), there was one monitor in elevated terrain and two monitors in flat terrain with a full year of data. Both the North Dakota and Eastman sites featured observations of the design concentration being within about 10% of the mean design concentration over all monitors. Modeling results using default options in AERMOD for both of these sites indicated a large spread of the predictions, with predictions in high terrain exceeding observations by more than a factor of 2. In contrast, the predictions in flat terrain, while higher than observations, showed a lower overprediction bias. The use of low wind speed improvements in AERMOD (beta u_* in AERMET and an elevated minimum σ_v value) did improve model predictions for both databases.

The conclusions from the review of the meteorological conditions associated with peak observations, provided in the supplemental file called "Gibson Meteorological Conditions Resulting in Top 25 Concentrations," are as follows:

- Peak observations for the Mt. Carmel and East Mt. Carmel monitors occur during both light wind convective conditions and strong wind conditions (near neutral, both daytime and nighttime).
- Nighttime peaks that are noted at Mt. Carmel and East Mt. Carmel could be due to downwash effects with southerly winds.
- Gibson Tower and Shrodt monitors were in directions with minimal downwash effects; therefore, the peak impacts at these monitors occur with convective conditions.
- The Gibson Tower and Shrodt monitor peak observation conditions were similarly mixed for wind speeds, but they were consistently occurring during the daytime only.

AERMOD (hourly) modeling runs and SHARP runs are generally consistent with the patterns of observed conditions for Shrodt and Gibson Tower monitors. Except for downwash effects, the peak concentrations were all observed and predicted during daytime hours. There are similar AERMOD results for Mt. Carmel and East Mt. Carmel, except that there are more nighttime periods and periods with strong wind conditions.

As noted earlier, AERMOD tends to focus its peak predictions for tall stacks in simple terrain (those not affected by building downwash) for conditions with low mixing heights in the morning. However, a more detailed review of these conditions indicates that the high predictions are not simply due to plumes trapped within the convective mixed layer, but instead due to plumes that initially penetrate the mixing layer, but then emerge (after a short travel time) into the convective boundary layer in concentrated form with a larger-than-expected vertical spread. Tests of this condition were undertaken by Dr. Ken Rayner of the Western Australia Department of Environmental Regulation (2013), who found the same condition occurring for tall stacks in simple terrain for a field study database in his province. Rayner found that AERMOD tended to overpredict peak concentrations by a factor of about 50% at a key monitor, while with the penetrated plume removed from consideration, AERMOD would underpredict by about 30%. Therefore, the correct treatment might be a more delayed entrainment of the penetrated plume into the convective mixed layer. Rayner's basic conclusions were:

- A plume penetrates and disperses within a 1-hr time step in AERMOD, while in the real world, dispersion of a penetrated puff may occur an hour or more later, after substantial travel time.
- A penetrated plume initially disperses via a vertical Gaussian formula, not a convective probability density function. Because penetrated puffs typically have a very small vertical dispersion, they are typically fully entrained (in AERMOD) in a single hour by a growing mixed layer, and dispersion of a fully entrained puff is via convective mixing, with relatively rapid vertical dispersion, and high ground-level concentrations.

Conclusions and Recommendations for Further Research

This study has addressed additional evaluations for low wind conditions involving tall stack releases for which multiple years of concurrent emissions, meteorological data, and monitoring data were available. The modeling cases that were the focus of this study involved applications with only one level of meteorological data and no direct turbulence measurements or vertical temperature gradient observations.

For the North Dakota evaluation, the AERMOD model overpredicted, using the design concentration as the metric for each monitor. For the relatively low elevation monitors, the results were similar for both the default and beta options and are within 5–30% of the monitored concentrations depending on the model option. The modeling result for the elevated DGC#17 monitor showed that this location is sensitive to terrain, as the ratio of modeled to monitored concentration is over 2. However, when this location was modeled with the low wind beta option, the ratio was notably better, at less than 1.3. Furthermore, the low wind speed beta option changed the AERMOD's focus on peak predictions conditions from mostly nighttime to mostly daytime periods, somewhat more in line with observations. Even for a minimum σ_v as high as 0.5 m/sec, all of the AERMOD modeling results were conservative or relatively unbiased (for the design concentration). The North Dakota evaluation results for the sub-hourly (SHARP) modeling were, on average, relatively unbiased, with a predicted-to-observed design concentration ratio ranging from 0.89 to 1.2. With a 10% tolerance in the SO_2 monitored values, we find that the SHARP performance is quite good. Slightly higher SHARP predictions would be expected if AERMOD were run with the LOWWIND1 option deployed.

For the Gibson flat terrain evaluation, AERMOD with hourly averaged meteorological data overpredicted at three of the four monitors between 30 and 50%, and about 10% at the fourth monitor. The AERMOD results did not vary much with the various low wind speed options in this flat terrain setting. AERMOD with sub-hourly meteorological data (SHARP) had the best (least biased predicted-to-observed ratio of design concentrations) performance among the five cases modeled. Over the four monitors, the range of predicted-to-observed ratios for SHARP was a narrow one, ranging from a slight underprediction by 2% to an overprediction by 14%. All other modeling options had a larger range of results.

The overall findings with the low wind speed testing on these tall stack databases indicate that:

- The AERMOD low wind speed options have a minor effect for flat terrain locations.
- The AERMOD low wind speed options have a more significant effect with AERMOD modeling for elevated terrain locations, and the use of the LOWWIND2 option with a minimum σ_v on the order of 0.5 m/sec is appropriate.
- The AERMOD sub-hourly modeling (SHARP) results are mostly in the unbiased range (modeled to observed design concentration ratios between 0.9 and 1.1) for the two databases tested with that option.
- The AERMOD low wind speed options improve the consistency of meteorological conditions associated with the highest observed and predicted concentration events.

Further analysis of the low wind speed performance of AERMOD with either the SHARP procedure or the use of the minimum σ_v specifications by other investigators is encouraged. However, SHARP can only be used if sub-hourly meteorological data is available. For Automated Surface Observing Stations (ASOS) with 1-min data, this option is a possibility if the 1-min data are obtained and processed.

Although the SHARP results reported in this paper are encouraging, further testing is recommended to determine the optimal sub-hourly averaging time (no less than 10 min is recommended) and whether other adjustments to AERMOD (e.g., total disabling of the meander option) are recommended. Another way to implement the sub-hourly information in AERMOD and to avoid the laborious method of running AERMOD several times for SHARP would be to include a distribution, or range, of the sub-hourly wind directions to AERMOD so that the meander calculations could be refined.

For most modeling applications that use hourly averages of meteorological data with no knowledge of the sub-hourly wind distribution, it appears that the best options with the current AERMOD modeling system are to implement the AERMET beta u_* improvements and to use a minimum σ_v value on the order of 0.5 m/sec/sec.

It is noteworthy that EPA has recently approved (EPA, 2015) as a site-specific model for Eastman Chemical Company the use of the AERMET beta u_* option as well as the LOWWIND2 option in AERMOD with a minimum σ_v of 0.4 m/sec. This model, which was evaluated with site-specific meteorological data and four SO_2 monitors operated for 1 year, performed well in flat terrain, but overpredicted in elevated terrain, where a minimum σ_v value of 0.6 m/sec actually performed better. This would result in an average value of the minimum σ_v of about 0.5 m/sec, consistent with the findings of Hanna (1990).

The concept of a minimum horizontal wind fluctuation speed on the order of about 0.5 m/sec is further supported by the existence of vertical changes (shears) in wind direction (as noted by Etling, 1990) that can result in effective horizontal shearing of a plume that is not accounted for in AERMOD. Although we did not test this concept here, the concept of vertical wind shear effects, which are more prevalent in decoupled stable conditions than in well-mixed convective conditions, suggests that it would be helpful to have a "split minimum σ_v" approach in AERMOD that enables the user to specify separate minimum σ_v values for stable and unstable conditions. This capability would, of course, be backward-compatible to the current minimum σ_v specification that applies for all stability conditions in AERMOD now.

Supplemental Material

Supplemental data for this article can be accessed at the publisher's website

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Attachment C

Evaluation of Low Wind Modeling Approaches for Two Tall-Stack Databases with AERMET ADJ_U* and AERMOD LOWWIND3 Options

Evaluation of Low Wind Modeling Approaches for Two Tall-Stack Databases with AERMET ADJ_U* and AERMOD LOWWIND3 Options

Olga Samani and Robert Paine, AECOM

August 22, 2015

Introduction

In a proposed rulemaking published in the July 29, 2015 Federal Register (80 FR 45340), the United States Environmental Protection Agency (EPA) released a revised version of AERMOD (15181), which replaces the previous version of AERMOD dated 14134. EPA proposed refinements to its preferred short-range model, AERMOD, involving low wind conditions. These refinements involve an adjustment to the computation of the friction velocity ("ADJ_U*") in the AERMET meteorological pre-processor and a higher minimum lateral lateral wind speed standard deviation, sigma-v (σ_v), as incorporated into the "LOWWIND3" option. The proposal indicates that "the LOWWIND3 BETA option increases the minimum value of sigma-v from 0.2 to 0.3 m/s, uses the FASTALL approach to replicate the centerline concentration accounting for horizontal meander, but utilizes an effective sigma-y and eliminates upwind dispersion".[1]

This document describes the evaluation of the combined ADJ_U* and LOWWIND3 options as recommended by EPA for incorporated as default options in AERMOD version 15181 on two previously evaluated tall-stack databases as described by Paine et al. (2015)[2]. Here we compare the model evaluation results of these new options relative to the various modeling options previously tested model options in AERMOD version 14134.

Modeling Options and Databases for Testing

The meteorological data, emissions, and receptors used in this analysis were identical to Paine et al. (2015) analysis. Two AERMET/AERMOD model configurations were tested for the two field study databases.

- AERMET and AERMOD in default mode with version 15181.
- Low wind beta option for AERMET (ADJ_U*) and the LOWWIND3 option for AERMOD (LOWWIND3 automatically sets minimum σ_v value to 0.3 m/sec) with version 15181.

The results were compared to the five AERMET/AERMOD model configurations previously tested in Paine et al. (2015) with version 13350.

- AERMET and AERMOD in default mode.

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[1] Addendum User's Guide for the AMS/EPA Regulatory Model – AERMOD http://www.epa.gov/ttn/scram/models/aermod/aermod_userguide.zip

[2] Paine, R., Samani, O., Kaplan, M. Knipping, E., and Kumar, N. Evaluation of Low Wind Modeling Approaches for Two Tall-Stack Databases. Pending publications (as of August, 2015) in the Journal of Air & Waste Management Association.

- Low wind beta option for AERMET and default options for AERMOD (minimum σ_v value of 0.2 m/sec).
- Low wind beta option for AERMET and the LOWWIND2 option for AERMOD (minimum σ_v value of 0.3 m/sec).
- Low wind beta option for AERMET and the LOWWIND2 option for AERMOD (minimum σ_v value of 0.5 m/sec).
- Low wind beta option for AERMET and AERMOD run in sub-hourly mode (SHARP).

All model applications used one wind level, a minimum wind speed of 0.5 m/sec, and also used hourly average meteorological data with the exception of SHARP applications.

The Mercer County, North Dakota and Gibson Generating Station, Indiana databases were selected for the low wind model evaluation due to the following attributes:

- They feature multiple years of hourly SO_2 monitoring at several sites.
- Emissions are dominated by tall stack sources that are available from continuous emission monitors.
- They include sub-hourly meteorological data so that the SHARP modeling approach could be tested as well.
- There is representative meteorological data from a single-level station typical of (or obtained from) airport-type data.

Model Evaluation Results

The model evaluation employed metrics that address two basic areas:

1) 1-hour SO_2 NAAQS Design Concentration averaged over the years modeled at each monitor.

An operational metric that is tied to the form of the 1-hour SO_2 NAAQS is the "design concentration" (99th percentile of the peak daily 1-hour maximum values). This tabulated statistic was developed for each modeled case and for each individual monitor for each database evaluated.

2) Quantile-Quantile Plots for each monitor.

Operational performance of models for predicting compliance with air quality regulations, especially those involving a peak or near-peak value at some unspecified time and location, can be assessed with quantile-quantile (Q-Q) plots, which are widely used in AERMOD evaluations. Q-Q plots are created by independently ranking (from largest to smallest) the predicted and the observed concentrations from a set of predictions initially paired in time and space. A robust model would have all points on the diagonal (45-degree) line.

North Dakota Database Model Evaluation Procedures and Results

AERMOD was run for the two version 15181 configurations described above to compute the 1-hour daily maximum 99th percentile averaged over four years at the five ambient monitoring locations. A regional background of 10 µg/m^3 was added to the AERMOD modeled predictions, as determined from a review of rural monitors unaffected by local sources.

The 1-hour SO_2 design concentrations and ratios of the modeled (including the background of 10 µg/m^3) to monitored design concentrations for the North Dakota evaluation database are summarized in Table 1 and graphically plotted in Figure 2. The results of the Paine et al. (2015) model evaluation analysis for the five options (version 13350) is shown here along with the results of the new evaluation with AERMOD version 15181.

The overall results indicate that the predicted-to-observed ratios are generally greater than 1.0 and AERMOD version 15181 still over-predicts even with use of the proposed ADJ_u* and the LOWWIND3 options. The low wind options show improvement relative to the default options at all monitors, especially the monitor in higher terrain (DGC #17).

As shown in Figure 1, and as expected the results for the new model with low wind options are very close to the AERMOD version 14134 model with ADJ_U* and LOWWIND2. The results of the two model versions with default options are also very close to each other.

The Q-Q plots of the ranked top fifty daily maximum 1-hour SO_2 concentrations for predictions and observations are shown in Figure 2 (a-e) for AERMOD version 15181 default and low wind options. For the convenience of the reader, a vertical dashed line is included in each Q-Q plot to indicate the observed design concentration. In general, the Q-Q plots indicate the following:

- For all of the monitors, to the left of the design concentration line, the ranked predictions are at or higher than observations.
- To the right of the design concentration line, some of the ranked modeled values are lower than the ranked observed levels (although this is not the case for DGC #17).

Gibson Generating Station Database Model Evaluation Procedures and Results

AERMOD was run for the two version 15181 configurations described above to compute the 1-hour daily maximum 99th percentile averaged over three years at the four ambient monitors. A regional background of 18 µg/m^3 was added to the AERMOD modeled predictions.

The ratio of the modeled (including the background of 18 µg/m^3) to monitored concentrations is summarized in Table 2 and graphically plotted in Figure 3, and these ratios are generally greater than 1.0. The current version of AERMOD (version 15181) run in default mode showed no changes from the previous version's default results, still having over-predictions of about 10-50%. The proposed low wind options provided modest improvements in performance relative to the default options, while still showing an over-prediction tendency at each monitor.

The Q-Q plots of the ranked top fifty daily maximum 1-hour SO_2 concentrations for predictions and observations are shown in Figure 4 (a-d). As in the case of the North Dakota evaluation results, the Gibson plots indicate the following:

- For all of the monitors, to the left of the design concentration line, the ranked predictions are at or higher than observations.
- To the right of the design concentration line, some of the ranked modeled values are lower than the ranked observed levels (although this is not the case for Shrodt or Mt. Carmel for the low wind options).

Conclusions

The model evaluation results for the new version of AERMOD (version 15181) on the two databases showed that the proposed low wind options (ADJ_U* and LOWWIND3) perform better than the default options, while still overpredicting the design concentration at each monitor in both databases. Therefore, in conjunction with other evaluations that EPA reported at the 11th modeling conference on August 12, 2015, we recommend that EPA adopt the proposed low wind options default options, and allow their use in the interim for all modeling applications.

Table 1: North Dakota Ratio of Monitored to Modeled Design Concentrations*

Model Version	Test Case	Monitor	Observed	Predicted	Ratio
13350 (previously reported results)	Default AERMET, Default AERMOD	DGC#12	91.52	109.96	1.20
		DGC#14	95.00	116.84	1.23
		DGC#16	79.58	119.94	1.51
		DGC#17	83.76	184.48	2.20
		Beulah	93.37	119.23	1.28
15181	Default AERMET, Default AERMOD	DGC#12	91.52	110.77	1.21
		DGC#14	95.00	117.51	1.24
		DGC#16	79.58	120.30	1.51
		DGC#17	83.76	184.49	2.20
		Beulah	93.37	120.31	1.29
13350 (previously reported results)	Beta AERMET, Default AERMOD	DGC#12	91.52	109.96	1.20
		DGC#14	95.00	116.84	1.23
		DGC#16	79.58	119.94	1.51
		DGC#17	83.76	127.93	1.53
		Beulah	93.37	119.23	1.28
13350 (previously reported results)	Beta AERMET, AERMOD with LOWWIND2 σ_v = 0.3 m/sec	DGC#12	91.52	103.14	1.13
		DGC#14	95.00	110.17	1.16
		DGC#16	79.58	111.74	1.40
		DGC#17	83.76	108.69	1.30
		Beulah	93.37	106.05	1.14
13350 (previously reported results)	Beta AERMET, AERMOD with LOWWIND2 σ_v = 0.5 m/sec	DGC#12	91.52	95.86	1.05
		DGC#14	95.00	100.50	1.06
		DGC#16	79.58	106.65	1.34
		DGC#17	83.76	101.84	1.22
		Beulah	93.37	92.32	0.99
15181	Beta AERMET, AERMOD with LOWWIND3	DGC#12	91.52	98.75	1.08
		DGC#14	95.00	112.09	1.18
		DGC#16	79.58	111.20	1.40
		DGC#17	83.76	108.76	1.30
		Beulah	93.37	99.54	1.07
13350 (previously reported results)	SHARP	DGC#12	91.52	82.18	0.90
		DGC#14	95.00	84.24	0.89
		DGC#16	79.58	95.47	1.20
		DGC#17	83.76	88.60	1.06
		Beulah	93.37	86.98	0.93

*Design Concentration: 99th percentile peak daily 1-hour maximum, averaged over the years modeled and monitored.

Figure 1: North Dakota Ratio of Monitored to Modeled Design Concentration Values

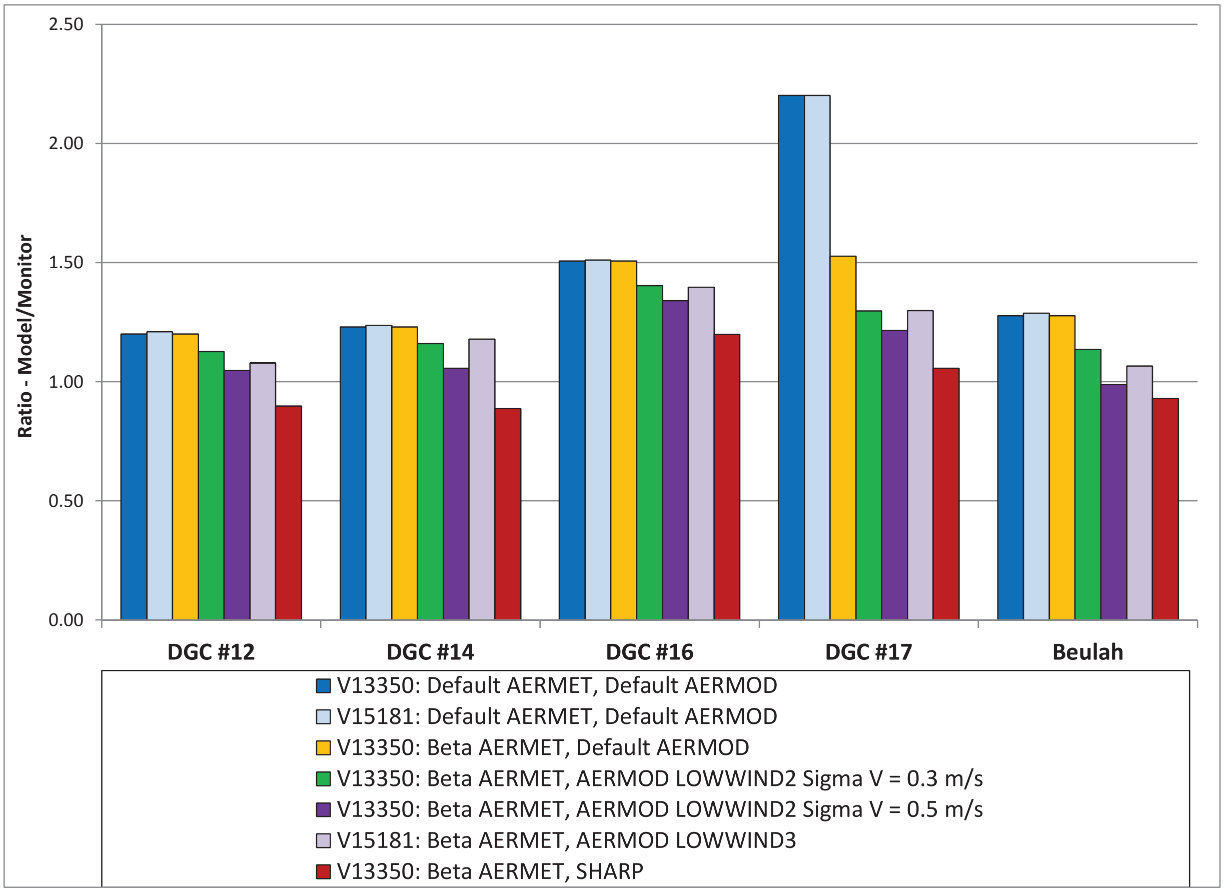
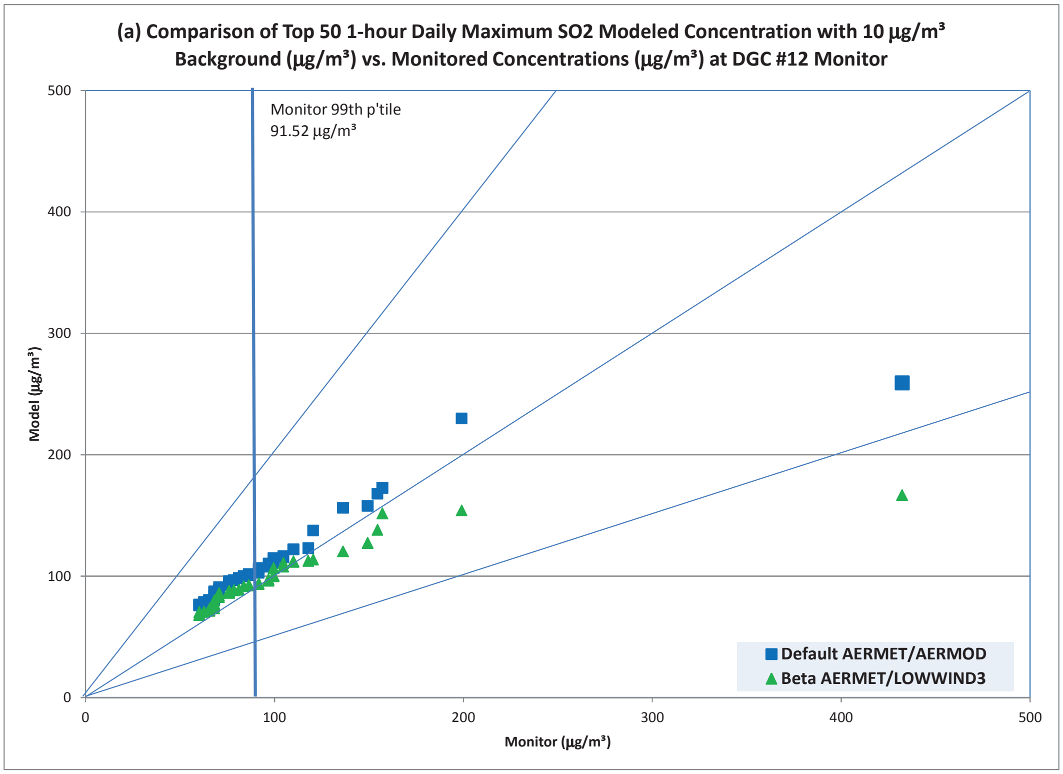
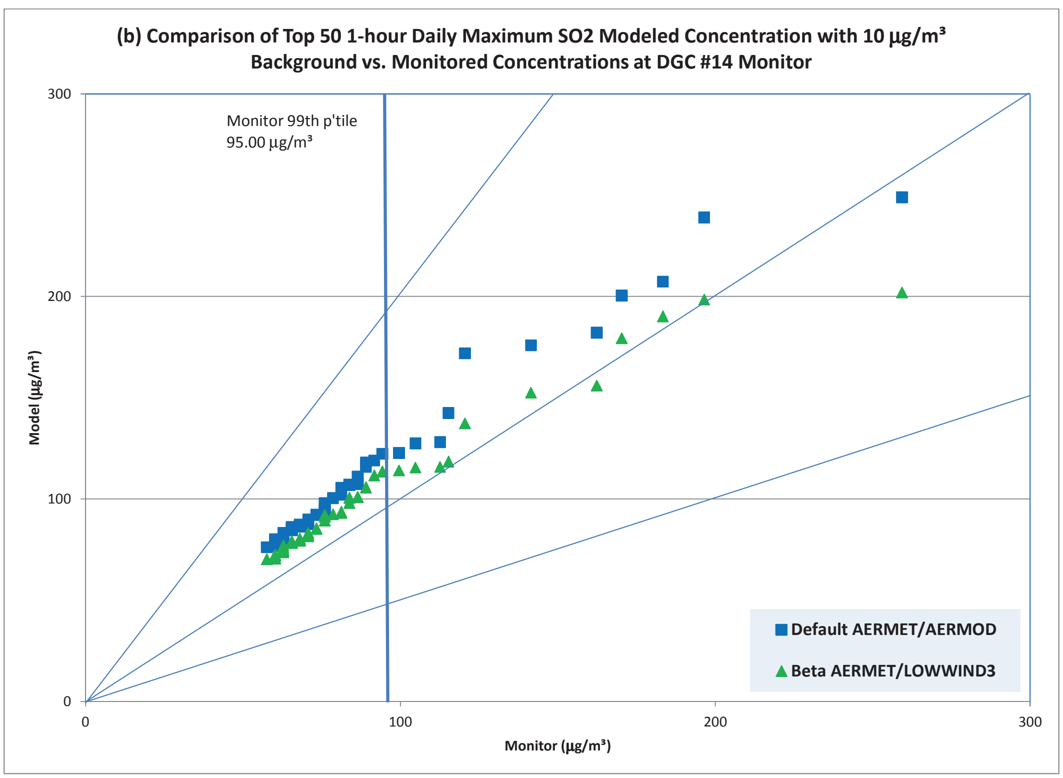
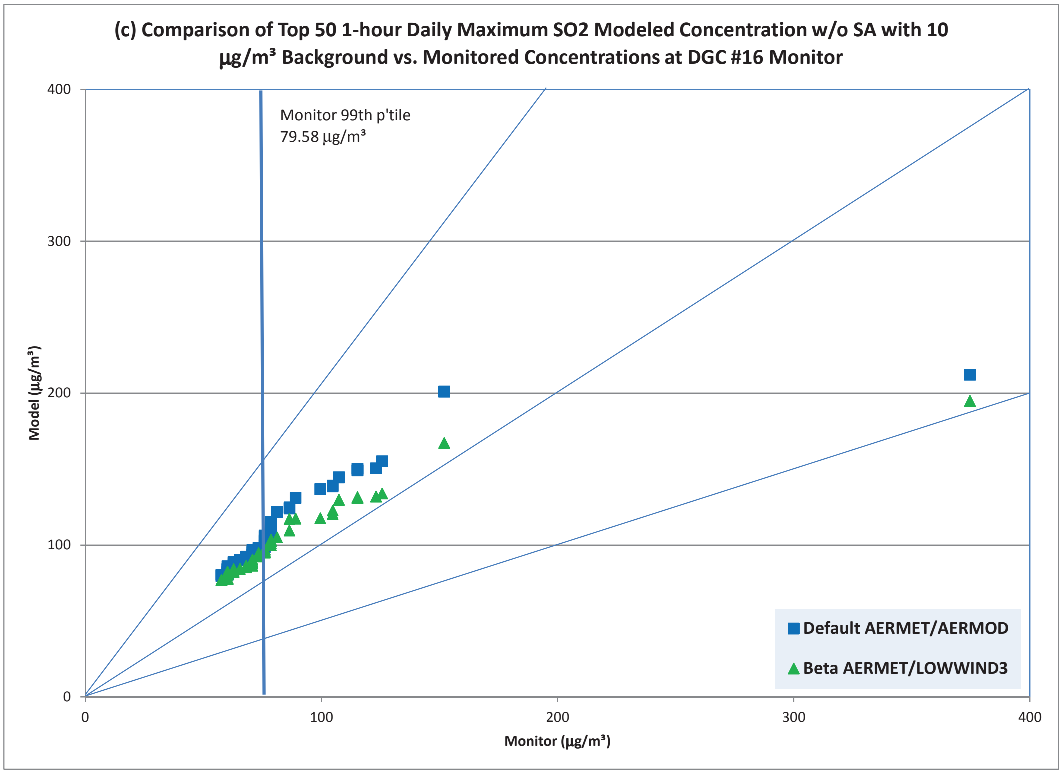
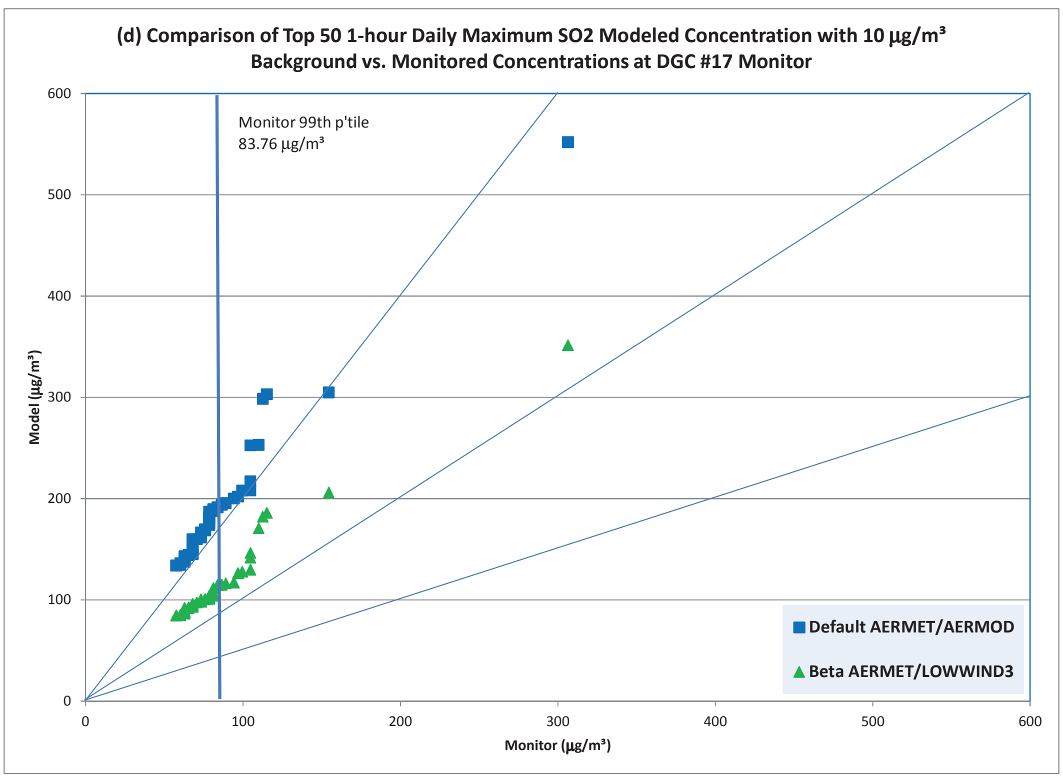


Figure 2: North Dakota Q-Q Plots: Top 50 Daily Maximum 1-hour SO_2 Concentrations. (a) DGC #12 Monitor. (b) DGC#14 Monitor. (c) DGC#16 Monitor. (d) DGC#17 Monitor. (e) Beulah Monitor






(c) Comparison of Top 50 1-hour Daily Maximum SO2 Modeled Concentration w/o SA with 10 µg/m³ Background vs. Monitored Concentrations at DGC #16 Monitor
Monitor 99th p'tile
79.58 µg/m³
Model (µg/m³)
Monitor (µg/m³)
0
100
200
300
400
Default AERMET/AERMOD
Beta AERMET/LOWWIND3


(d) Comparison of Top 50 1-hour Daily Maximum SO2 Modeled Concentration with 10 µg/m³ Background vs. Monitored Concentrations at DGC #17 Monitor
Monitor 99th p'tile
83.76 µg/m³
Model (µg/m³)
Monitor (µg/m³)
0
100
200
300
400
500
600
Default AERMET/AERMOD
Beta AERMET/LOWWIND3

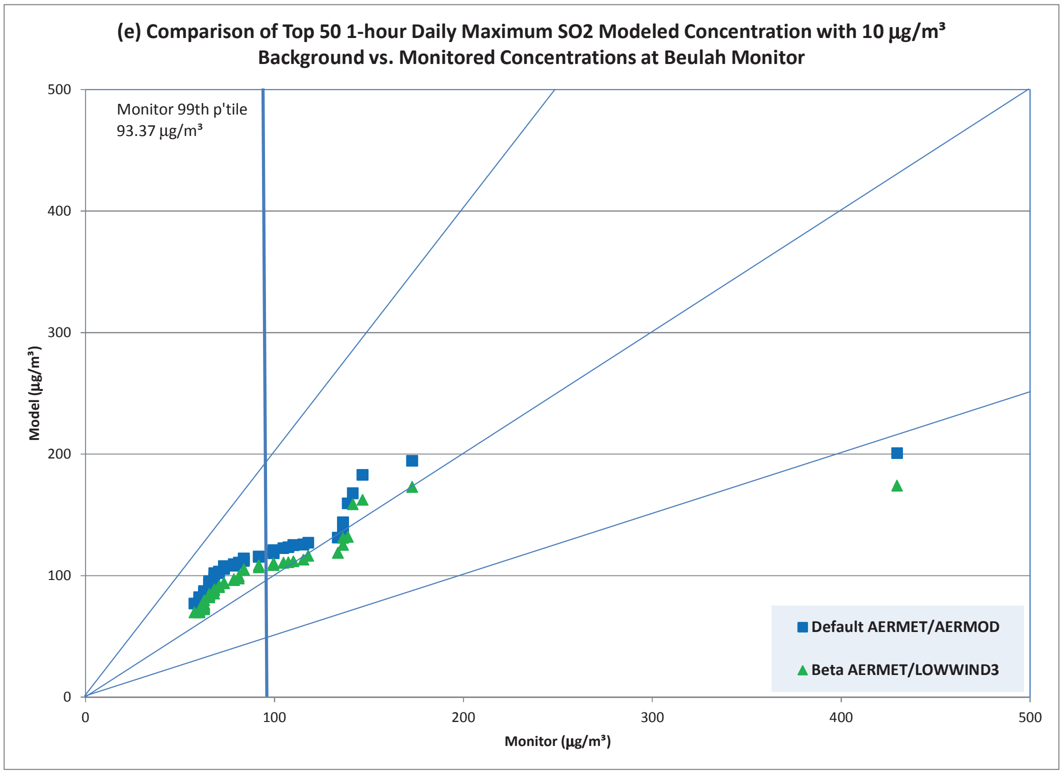

(e) Comparison of Top 50 1-hour Daily Maximum SO2 Modeled Concentration with 10 µg/m³
Background vs. Monitored Concentrations at Beulah Monitor
Monitor 99th p'tile
93.37 µg/m³
Model (µg/m³)
Monitor (µg/m³)
0
100
200
300
400
500
Default AERMET/AERMOD
Beta AERMET/LOWWIND3

Table 2: Gibson Ratio of Monitored to Modeled Design Concentrations*

Model Version	Test Case	Monitor	Observed	Predicted	Ratio
13350 (previously reported results)	Default AERMET, Default AERMOD	Mt. Carmel	197.25	278.45	1.41
		East Mt.	206.89	230.74	1.12
		Shrodt	148.16	189.63	1.28
		Gibson Tower	127.12	193.71	1.52
15181	Default AERMET, Default AERMOD	Mt. Carmel	197.25	278.45	1.41
		East Mt.	206.89	230.74	1.12
		Shrodt	148.16	189.63	1.28
		Gibson Tower	127.12	193.71	1.52
13350 (previously reported results)	Beta AERMET, Default AERMOD	Mt. Carmel	197.25	287.16	1.46
		East Mt.	206.89	229.22	1.11
		Shrodt	148.16	189.63	1.28
		Gibson Tower	127.12	193.71	1.52
13350 (previously reported results)	Beta AERMET, AERMOD with LOWWIND2 σ_v = 0.3 m/sec	Mt. Carmel	197.25	280.32	1.42
		East Mt.	206.89	224.65	1.09
		Shrodt	148.16	184.82	1.25
		Gibson Tower	127.12	192.22	1.51
13350 (previously reported results)	Beta AERMET, AERMOD with LOWWIND2 σ_v = 0.5 m/sec	Mt. Carmel	197.25	277.57	1.41
		East Mt.	206.89	224.65	1.09
		Shrodt	148.16	176.81	1.19
		Gibson Tower	127.12	192.22	1.51
15181	Beta AERMET, AERMOD with LOWWIND3	Mt. Carmel	197.25	276.12	1.40
		East Mt.	206.89	217.05	1.05
		Shrodt	148.16	175.42	1.18
		Gibson Tower	127.12	175.92	1.38
13350 (previously reported results)	SHARP	Mt. Carmel	197.25	225.05	1.14
		East Mt.	206.89	202.82	0.98
		Shrodt	148.16	136.41	0.92
		Gibson Tower	127.12	148.64	1.17

*Design Concentration: 99th percentile peak daily 1-hour maximum, averaged over the years modeled and monitored.

Figure 3: Gibson Ratio of Monitored to Modeled Design Concentration Values

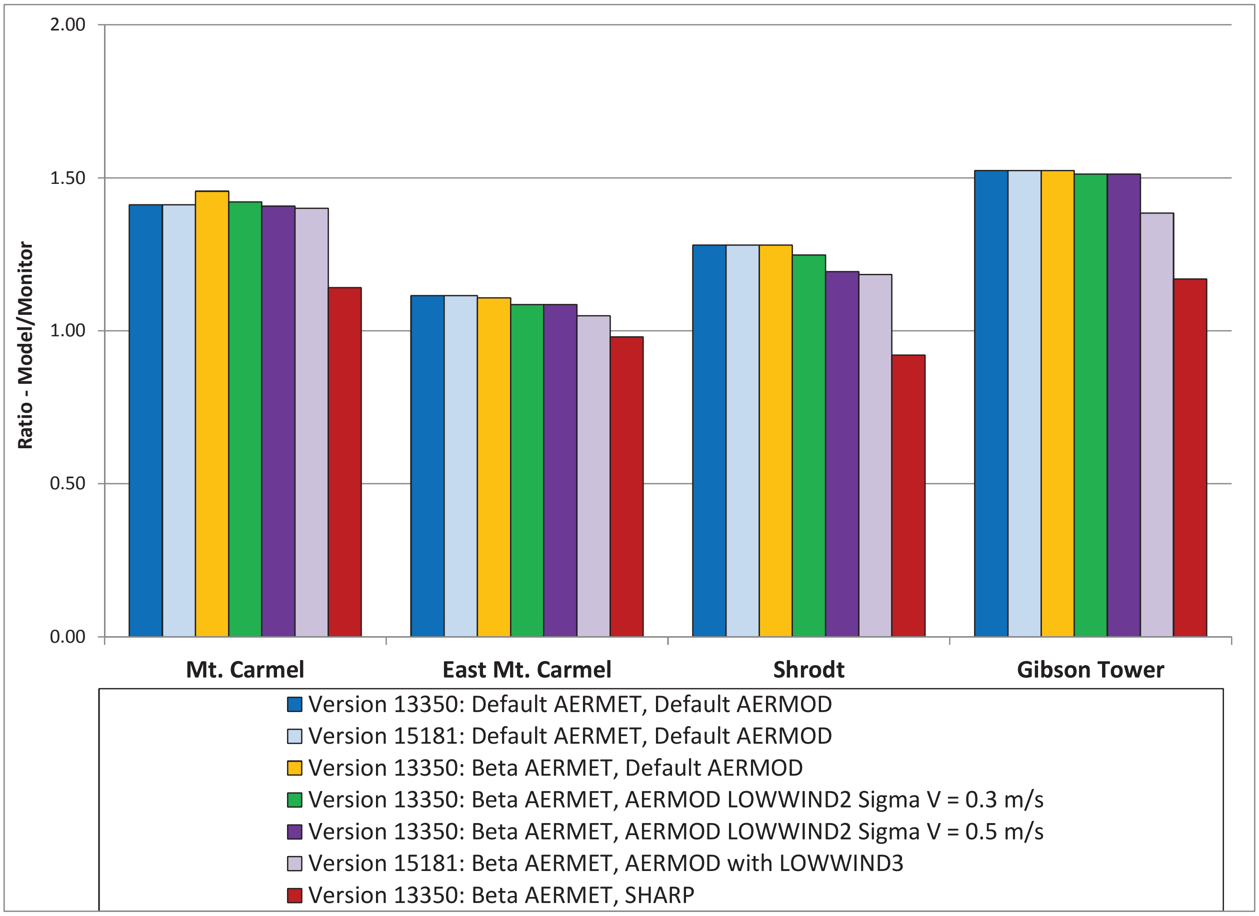
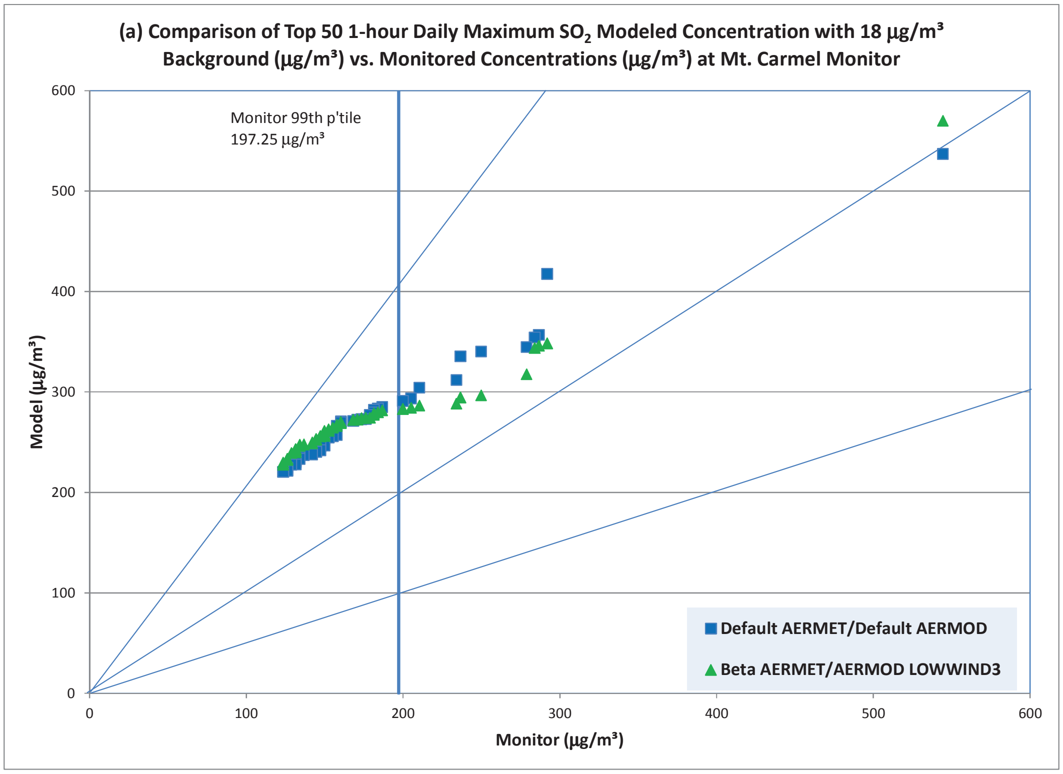
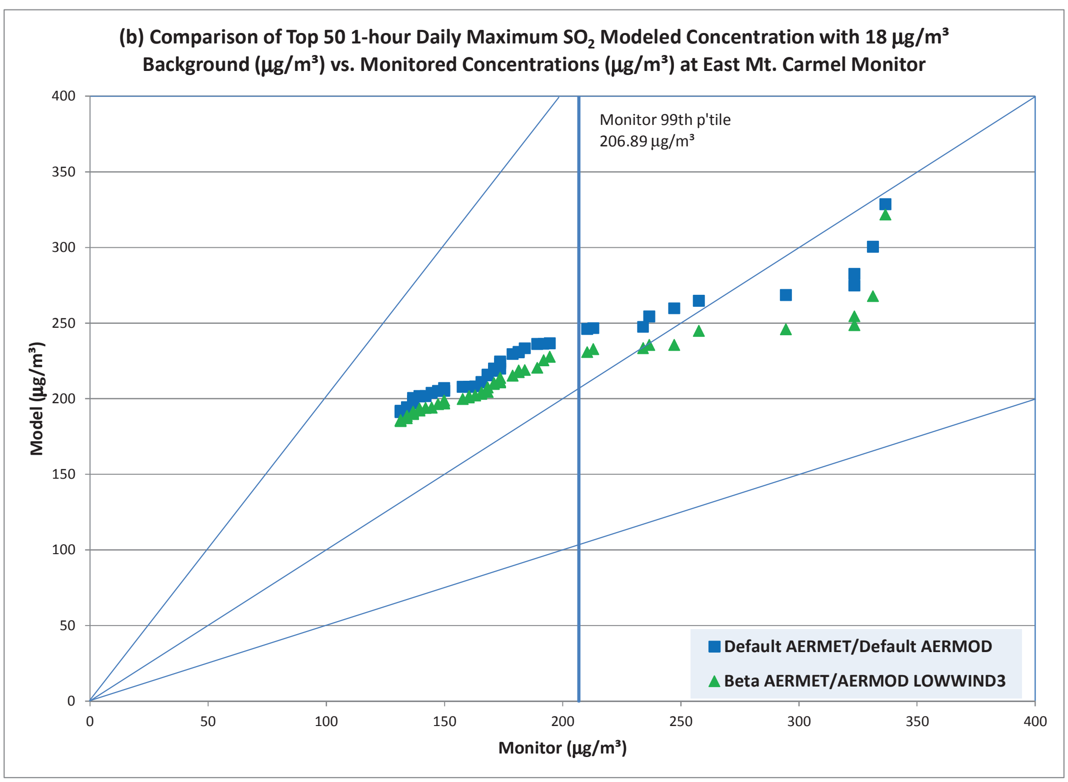
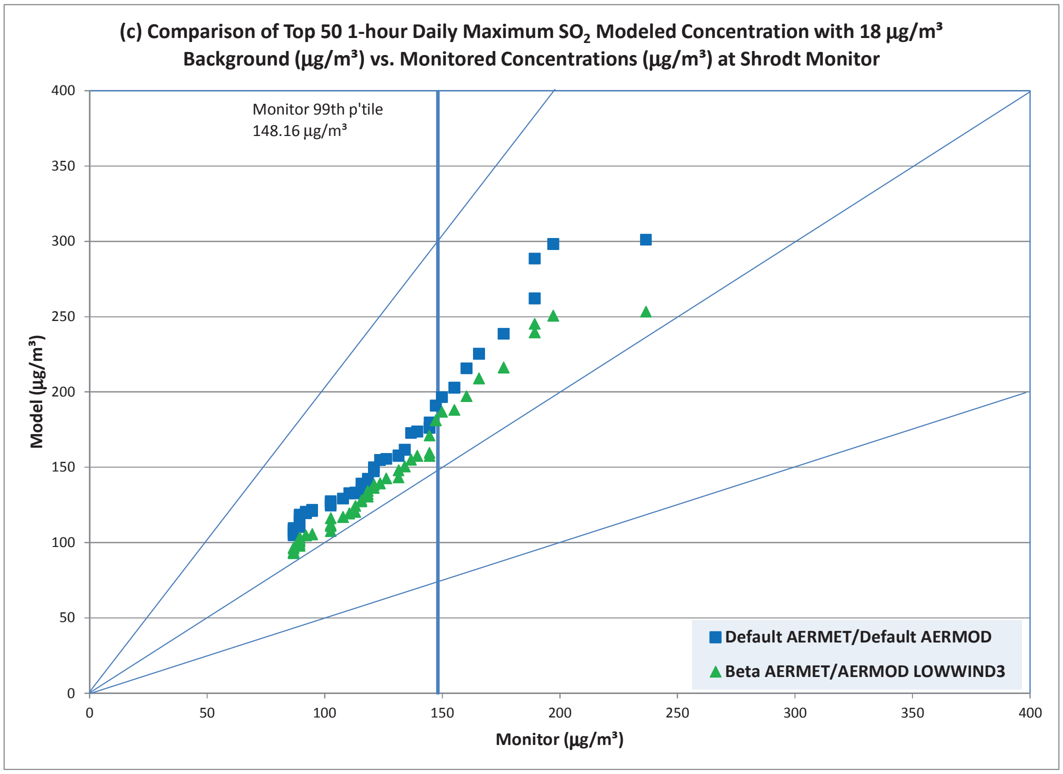


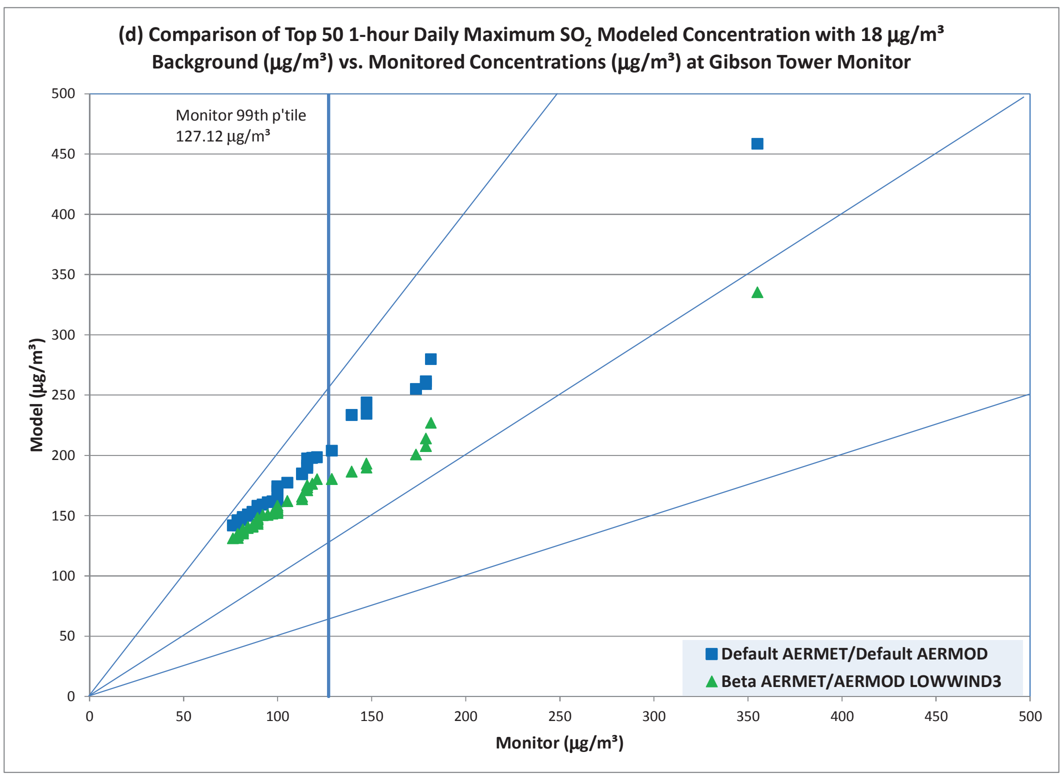
Figure 4: Gibson Q-Q Plots: Top 50 Daily Maximum 1-hour SO_2 Concentrations. (a) Mt. Carmel Monitor. (b) East Mt. Carmel Monitor. (c) Shrodt Monitor. (d) Gibson Tower Monitor







(c) Comparison of Top 50 1-hour Daily Maximum SO_2 Modeled Concentration with 18 µg/m³ Background (µg/m³) vs. Monitored Concentrations (µg/m³) at Shrodt Monitor
Monitor 99th p'tile
148.16 µg/m³
Model (µg/m³)
Monitor (µg/m³)
Default AERMET/Default AERMOD
Beta AERMET/AERMOD LOWWIND3



(d) Comparison of Top 50 1-hour Daily Maximum SO_2 Modeled Concentration with 18 µg/m³ Background (µg/m³) vs. Monitored Concentrations (µg/m³) at Gibson Tower Monitor
Monitor 99th p'tile
127.12 µg/m³
Model (µg/m³)
Monitor (µg/m³)
Default AERMET/Default AERMOD
Beta AERMET/AERMOD LOWWIND3

Attachment D

Characterization of 1-Hour SO2 Concentrations in the Vicinity of the Labadie Energy Center

Environment

Submitted to:
Schiff Hardin, LLP
Chicago, Illinois

Submitted by:
AECOM
Chelmsford, MA
60344380.100
September 2015

Characterization of 1-Hour SO_2 Concentrations in the Vicinity of the Labadie Energy Center

AECOM Environment
September 2015
Document No.: 60344380.100

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Characterization of 1-Hour SO_2 Concentrations in the Vicinity of the Labadie Energy Center

Prepared By: Mary Kaplan

Reviewed By: Robert Paine

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1.0 Introduction

The United States Environmental Protection Agency (EPA) is implementing the 2010 1-hour SO_2 National Ambient Air Quality Standard (NAAQS)[1] in an approach that involves either a dispersion modeling or monitoring approach to characterize local SO_2 concentrations near isolated emission sources. On March 20, 2015, EPA informed affected states that certain emission sources within their states will be addressed in an expedited[2] round of designations under the 1-hour SO_2 NAAQS due to terms of the SO_2 Consent Decree negotiated between the Sierra Club and EPA. The EPA intends to designate the affected areas as either unclassifiable/attainment, nonattainment or unclassifiable by July 2, 2016 after a review of available modeling or monitoring data to support the SO_2 concentration characterizations. Before then, the states need to recommend designations by September 18, 2015 and the EPA will review these recommendations and issue their comments on these recommendations to the states by January 22, 2016. After a public comment period on the state recommendations and EPA comments ending March 4, 2016 and final input from the states by April 8, 2016, EPA will issue their final designation findings by July 2, 2016.

One of the affected sources is the Labadie Energy Center, located about 50 kilometers west of St. Louis, along the Missouri River (see Figure 1-1 for a map showing the source location and terrain in the vicinity). The purpose of this report is to provide information to the Missouri Department of Natural Resources (MDNR) regarding the results of a dispersion modeling characterization of SO_2 concentrations around Labadie. The plant's 700-ft (213-m) stacks are well above the surrounding terrain (less than 120 m of relief), so that any dispersion modeling application involves simple terrain. As this report describes, the dispersion modeling analysis was conducted using both the current regulatory defaults and using proposed EPA changes to the preferred modeling approaches.

1.1 Report Organization

Section 2 of this report describes the Labadie Energy Center and the other sources modeled. This section also describes the source of regional monitoring data that is used to represent distant source impacts. Section 3 describes the dispersion model approaches used in this study: the current default AERMOD modeling approach as well as the use of EPA-proposed low wind improvements to AERMOD. Justification for the use of the low wind improvements is provided in appendices to the report. Section 4 of the report describes the modeling results, and indicates that with modeling conducted in accordance with the Modeling Technical Assistance Document[3], the characterization of SO_2 concentrations results in a finding of NAAQS attainment. Appendices A, B, and C provide documentation for an interim use of the low wind options as a non-default model. Appendix D compares Jefferson City and Spirit of St. Louis airport data to historical tall-tower meteorological data taken near Labadie.

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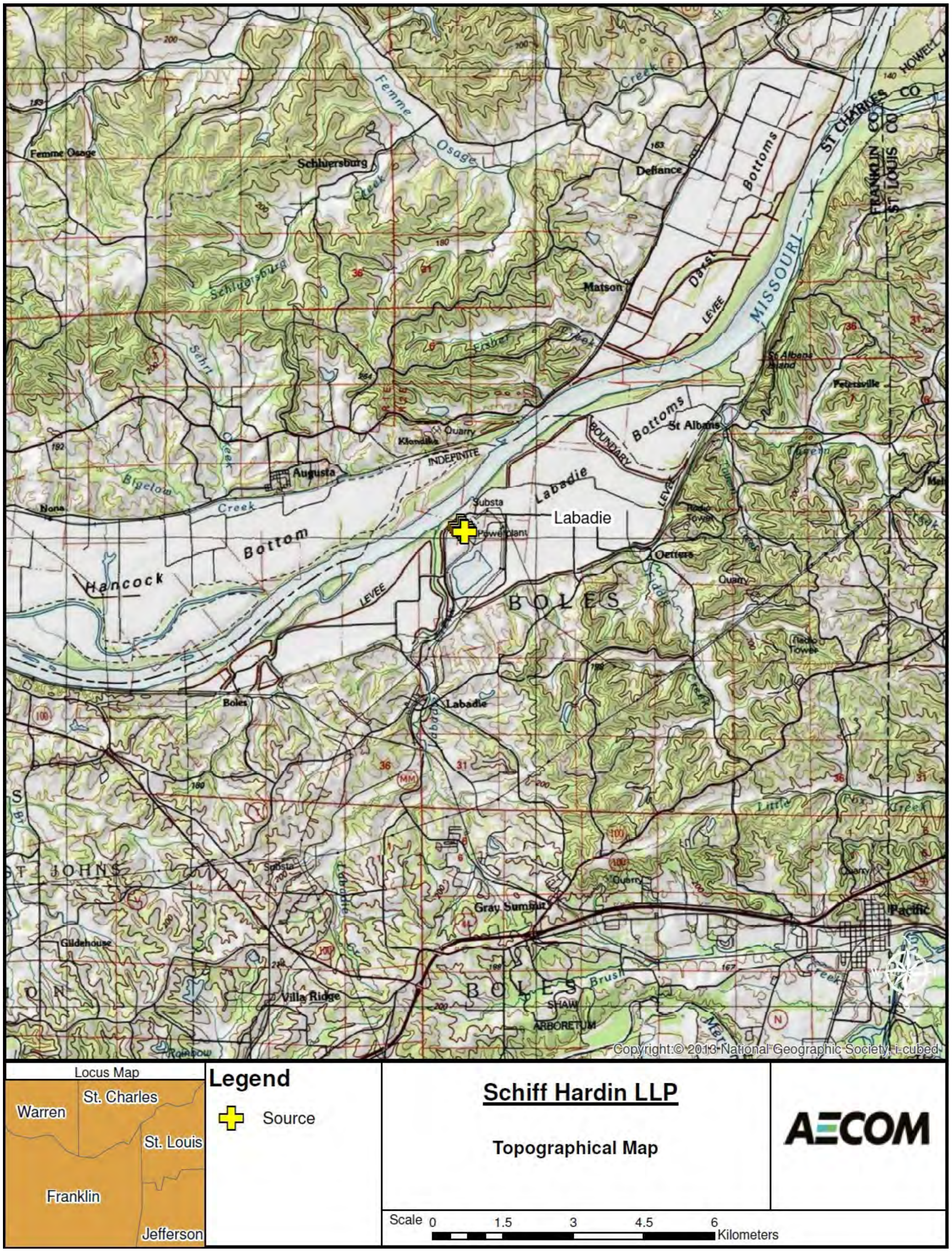
[1] 75 FR 35571 is the final rule for the 2010 SO_2 NAAQS.

[2] Information on the "SO_2 Consent Decree" is available at http://www.epa.gov/so2designations/data.html.

[3] http://www.epa.gov/airquality/sulfurdioxide/pdfs/SO2ModelingTAD.pdf.

Figure 1-1 Topographical Map Showing Labadie Site Location



2.0 Description of Modeled Emission Sources

2.1 Labadie Energy Center

Labadie Energy Center is a 2,407-megawatt coal-fired power plant located in Labadie, Missouri. The station operates four boilers exhausting through three 213-meter tall stacks (Units 3 and 4 emit from a dual-flue stack), as shown in Figure 2-1. The area surrounding Labadie is considered rural with mostly simple terrain out to approximately 50 km from the facility.

Figure 2-1: Labadie Energy Center Photograph

Credit: St. Louis Post-Dispatch; see http://www.stltoday.com/news/opinion/columns/the-platform/labadie-power-plant/image_740dccb2-a72b-11df-ac73-00127992bc8b.html.

2.2 Regional Background

According to the EPA March 1, 2011 Memorandum[4] and the analysis presented at the 2011 EPA modeling workshop[5], selection of regional background sources should be limited to 10 kilometers from the source location. Figure 2-2 shows the 10-km radius circle around Labadie Energy Center and two

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[4] http://www.epa.gov/scram001/guidance/clarification/Additional_Clarifications_AppendixW_Hourly-NO2-NAAQS_FINAL_03-01-2011.pdf

[5] Page 5 http://www.cleanairinfo.com/regionalstatelocalmodelingworkshop/archive/2011/Presentations/6-Thursday_AM/6-3_AB-3_Presentation_at_EPA_Modeling_Workshop.pdf

small SO_2 emission sources that emit less than 1 TPY that MDNR considered in this review. The nearest large SO_2 sources are more than 28 km away, which would place them at a distance for which a uniform background influence would be expected. Therefore, these more distant sources would not be expected to interact with Labadie to cause a significant concentration gradient near Labadie. The total concentration for 1-hour SO_2 NAAQS compliance was computed by adding the modeled concentration to the regional background concentrations from the Nilwood, Illinois monitor, shown in Figure 2-3.

The background concentration was calculated as a 3-year (2012-2014) average of the maximum concentration by season and hour-of-day and added internally in AERMOD to the AERMOD-predicted concentration for comparison with the 1-hour SO_2 National Ambient Air Quality Standard (NAAQS) of 196.5 $\mu g/m^3$. The Nilwood seasonal SO_2 concentrations are displayed in Figure 2-4. Previous modeling by MDNR used a constant background value of 9 ppb derived from data collected at the East St. Louis, Illinois SO_2 monitor. MDNR excluded data from a large sector based on a wind trajectory analysis to avoid double counting of modeled sources. In this case, where Labadie is in a rural area with no other nearby sources, using background data from an urban monitor such as East St. Louis is conservative. The Nilwood monitor is located in a rural area of Illinois, similar to that of Labadie.

Figure 2-2: SO_2 Background Sources Included in Modeling

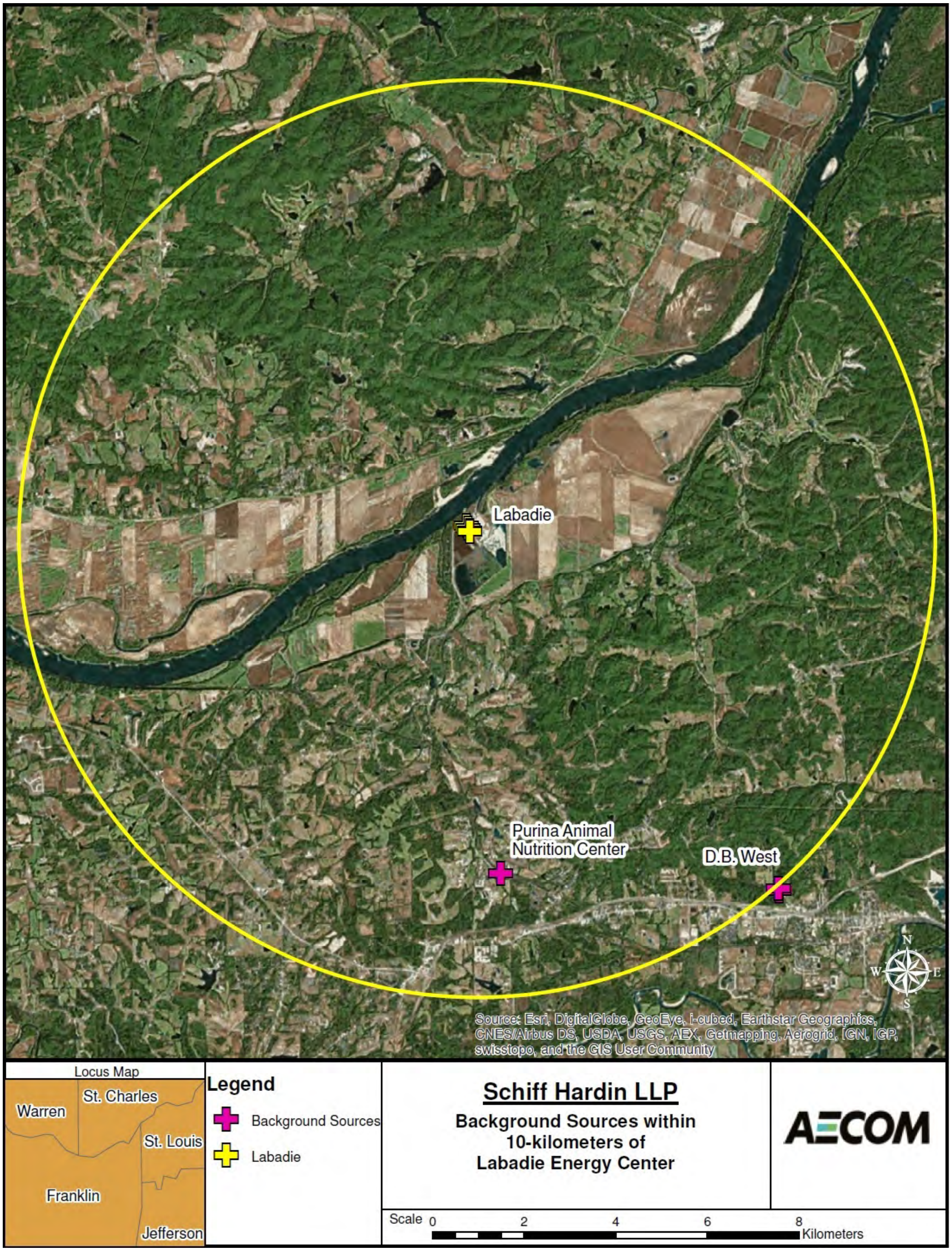


Figure 2-3 Nilwood Monitor Location with Respect to Labadie Energy Center

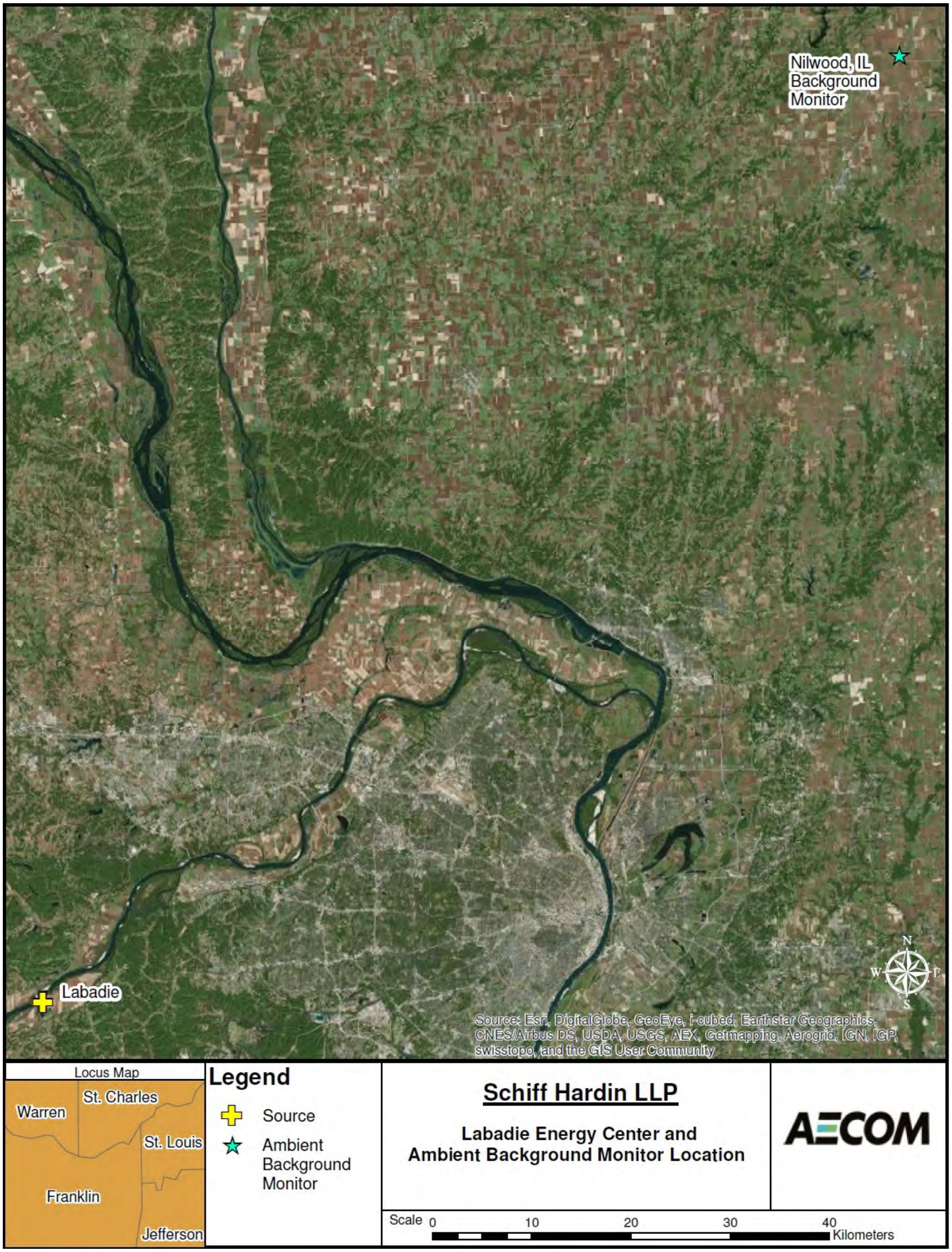
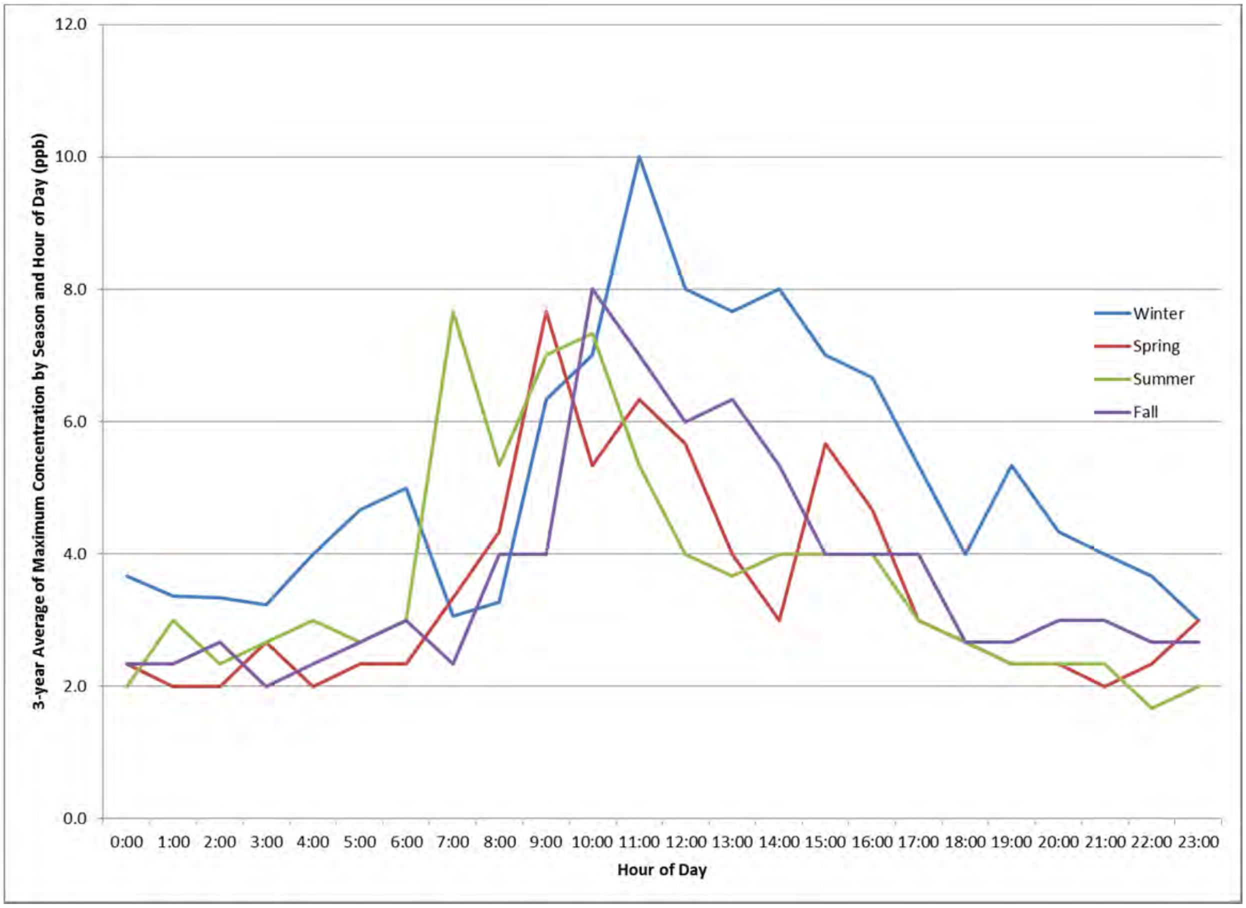


Figure 2-4: 2012-2014 3-year Average of Maximum Concentration by Season and Hour of Day at Nilwood SO_2 Monitor



3.0 Dispersion Modeling Approach

The suitability of an air quality dispersion model for a particular application is dependent upon several factors. The following selection criteria have been evaluated:

- stack height relative to nearby structures;
- dispersion environment;
- local terrain; and
- representative meteorological data.

The US EPA Guideline on Air Quality Models (Appendix W[6]) prescribes a set of approved models for regulatory applications for a wide range of source types and dispersion environments. Based on a review of the factors discussed below, the latest version of AERMOD (15181) was used to assess air quality impacts for the Labadie Energy Center. Previous modeling by MDNR used the previous version of AERMOD (version 14134). AERMOD version 15181 has "bug fixes" included that correct some errors in version 14134, so we have used the most recent version in this modeling.

In a proposed rulemaking published in the July 29, 2015 Federal Register (80 FR 45340), the United States Environmental Protection Agency (EPA) released a revised version of AERMOD (15181), which replaces the previous version of AERMOD dated 14134. EPA proposed refinements to its preferred short-range model, AERMOD, involving low wind conditions. These refinements involve an adjustment to the computation of the friction velocity ("ADJ_U*") in the AERMET meteorological pre-processor and a higher minimum lateral wind speed standard deviation, sigma-v (σ_v), as incorporated into the "LOWWIND3" option. The proposal indicates that "the LOWWIND3 BETA option increases the minimum value of sigma-v from 0.2 to 0.3 m/s, uses the FASTALL approach to replicate the centerline concentration accounting for horizontal meander, but utilizes an effective sigma-y and eliminates upwind dispersion".[7]

As this report describes, the dispersion modeling analysis was conducted using both the current regulatory defaults and using proposed EPA changes to the preferred modeling approaches with beta ADJ_U* and LOWWIND3 option. Documentation for an interim use of the low wind options as a non-default model are provided in Appendices A, B, and C. However, consistent with the EPA Appendix W, we anticipate that these proposed options will be promulgated as default options prior to the July 2, 2016 Consent Decree designation deadline, and therefore should be considered as more appropriate technical options to use at this time.

3.1 Good Engineering Practice Stack Height Analysis

Good engineering practice (GEP) stack height is defined as the stack height necessary to ensure that emissions from the stack do not result in excessive concentrations of any air pollutant as a result of

[6] http://www.epa.gov/ttn/scram/guidance/guide/appw_05.pdf

[7] Addendum User's Guide for the AMS/EPA Regulatory Model – AERMOD
http://www.epa.gov/ttn/scram/models/aermod/aermod_userguide.zip

atmospheric downwash, wakes, or eddy effects created by the source, nearby structures, or terrain features. AECOM used the BPIP downwash parameters provided by MDNR in their modeling files.

3.2 Dispersion Environment

The application of AERMOD requires characterization of the local (within 3 kilometers) dispersion environment as either urban or rural, based on a US EPA-recommended procedure that characterizes an area by prevalent land use. This land use approach classifies an area according to 12 land use types. In this scheme, areas of industrial, commercial, and compact residential land use are designated urban. According to US EPA modeling guidelines, if more than 50% of an area within a 3-km radius of the facility is classified as rural, then rural dispersion coefficients are to be used in the dispersion modeling analysis. Conversely, if more than 50% of the area is urban, urban dispersion coefficients are used. As shown in Figure 1-1, the 3-km area surrounding Labadie Energy Center is rural. Therefore, rural dispersion was assumed.

3.3 Model Receptor Grid and Terrain

AECOM used the same receptor grid that MDNR used in their 1-hour SO_2 modeling. Figures 3-1 and 3-2 show the receptor network used in this analysis.

3.4 Meteorological Data Processing

MDNR conducted an analysis to determine the most appropriate meteorological station for use in the 1-hour SO_2 modeling. Another nearby station, the Spirit of St. Louis airport in Chesterfield, was considered. Although this station is closer to Labadie and in an area along the Missouri River with a similar orientation, MDNR chose the Jefferson City airport due to land use similarities. It is also evident from a comparison to historical tall-tower data taken near Labadie that the Jefferson City airport wind pattern is more representative Labadie stack-top winds than the Spirit of St. Louis wind pattern is (see Appendix D). For a sensitivity study, AECOM used the Jefferson City and the Spirit of St. Louis airports in this modeling analysis and found that the Jefferson City modeled results were slightly higher than the Spirit of St. Louis airport results. Therefore, we reported results for the Jefferson City data.

Figure 3-3 shows the locations of the meteorological stations mentioned above in relation to the Labadie Energy Center. Figures 3-4 and 3-5 show the 3-year wind rose for each station considered in the analysis.

3.5 Emissions and Stack Parameters

Schiff Hardin provided AECOM with the latest three years (2012-2014) of hourly SO_2 emissions and hourly stack exhaust parameters for Labadie Energy Center. AECOM reviewed the hourly emission data for this period. For modeling purposes, from the data provided, we created a 3-year (2012-2014) hourly emissions, exit velocity, and temperature file.

Table 3-1 Labadie Stack Locations and 100% Load Exhaust Parameters

Unit	X (UTM83)	Y (UTM83)	Stack Height (m)	Exit Velocity (m/s)	Temperature (K)	Diameter (m)
1	688352.17	4270445.59	213.36	34.72	443.06	6.25
2	688387.01	4270400.40	213.36	35.56	442.49	6.25
3 & 4	688435.47	4270332.33	213.36	34.95	441.71	8.84[1]
(1) Equivalent diameter for merged flues						

Figure 3-1: Labadie Modeling Receptor Grid – Far Field

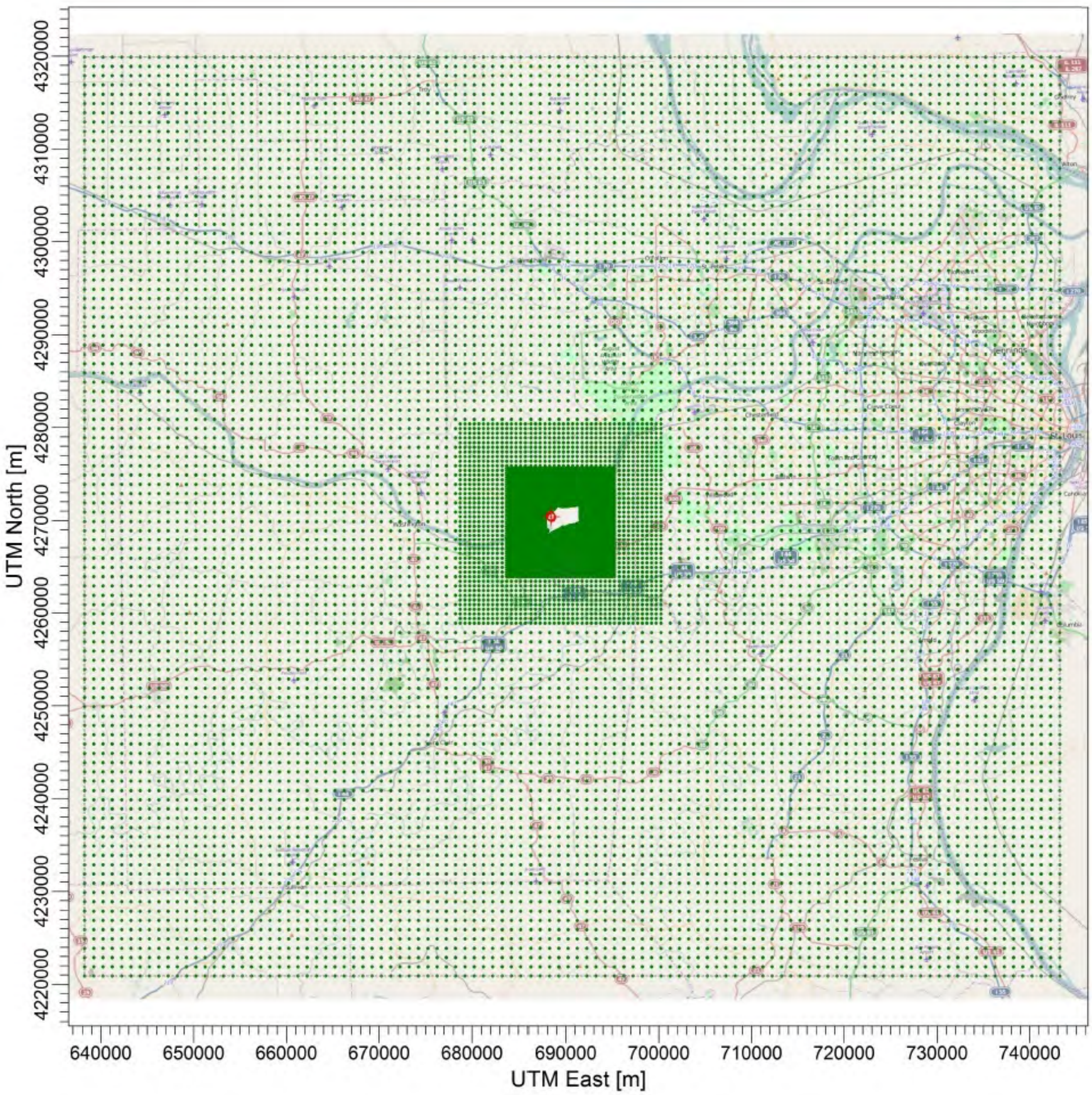


Figure 3-2: Labadie Modeling Receptor Grid – Near Field

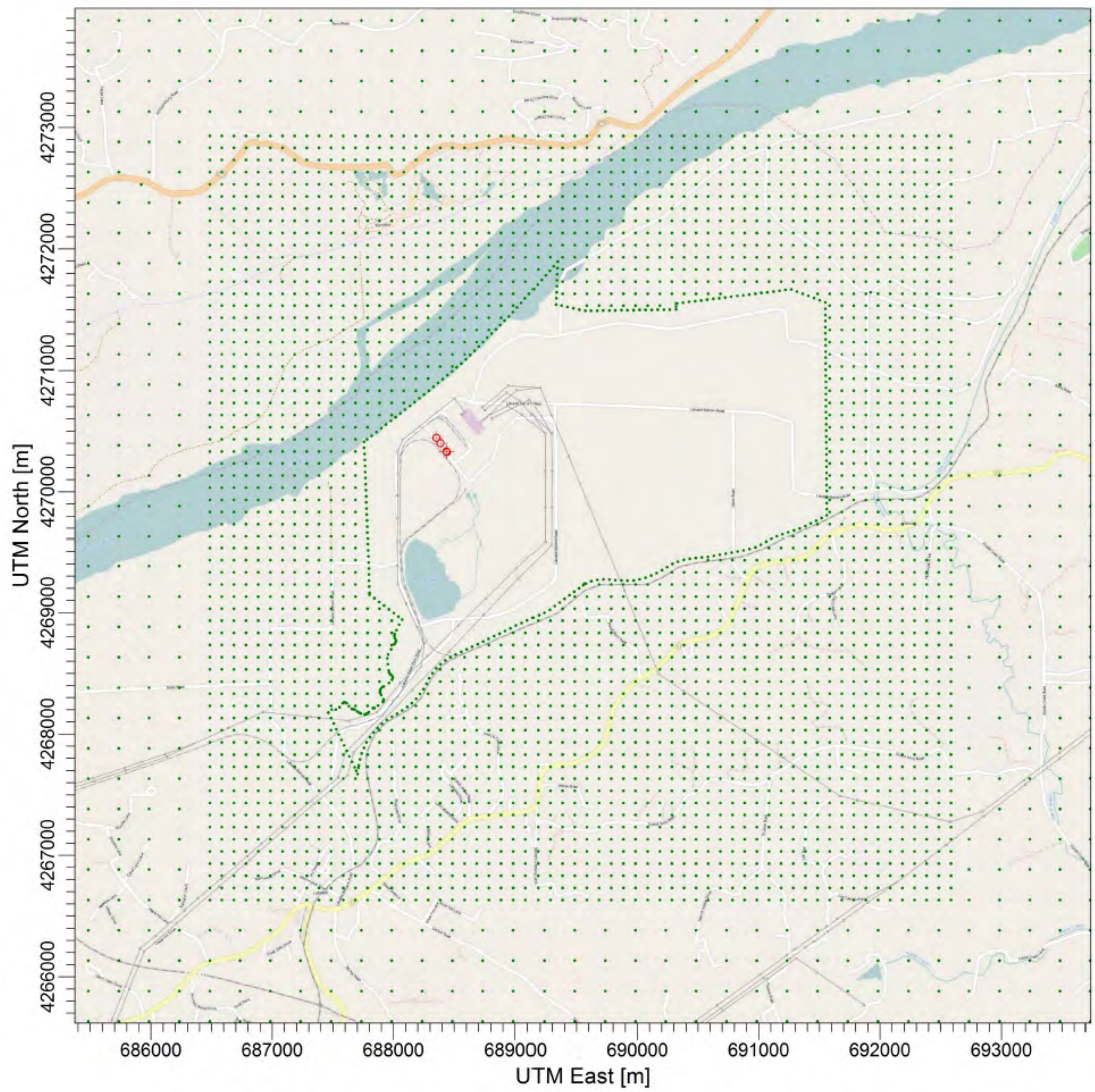


Figure 3-3: Location of Meteorological Stations Relative to Labadie Energy Center

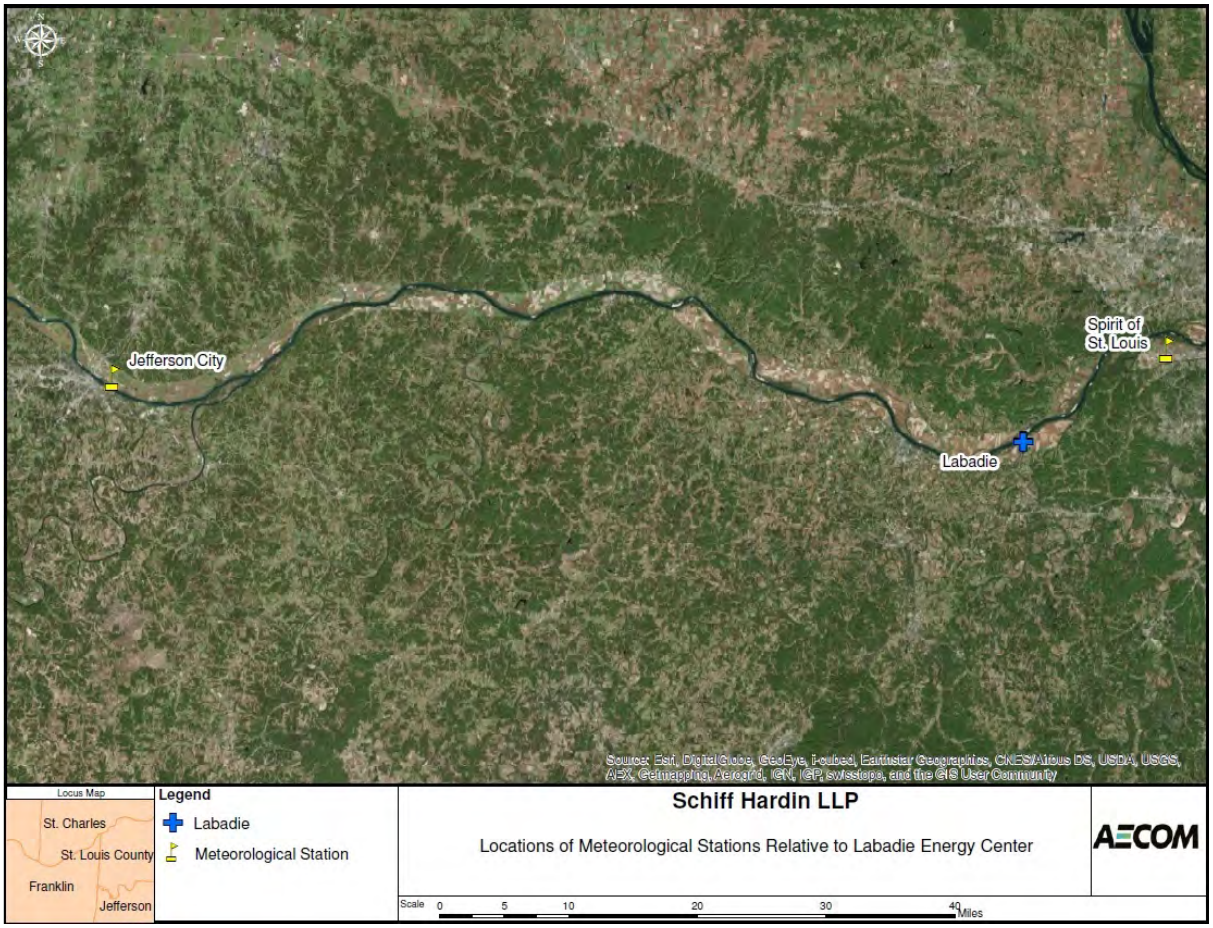


Figure 3-4: Jefferson City Wind Rose (2012-2014)

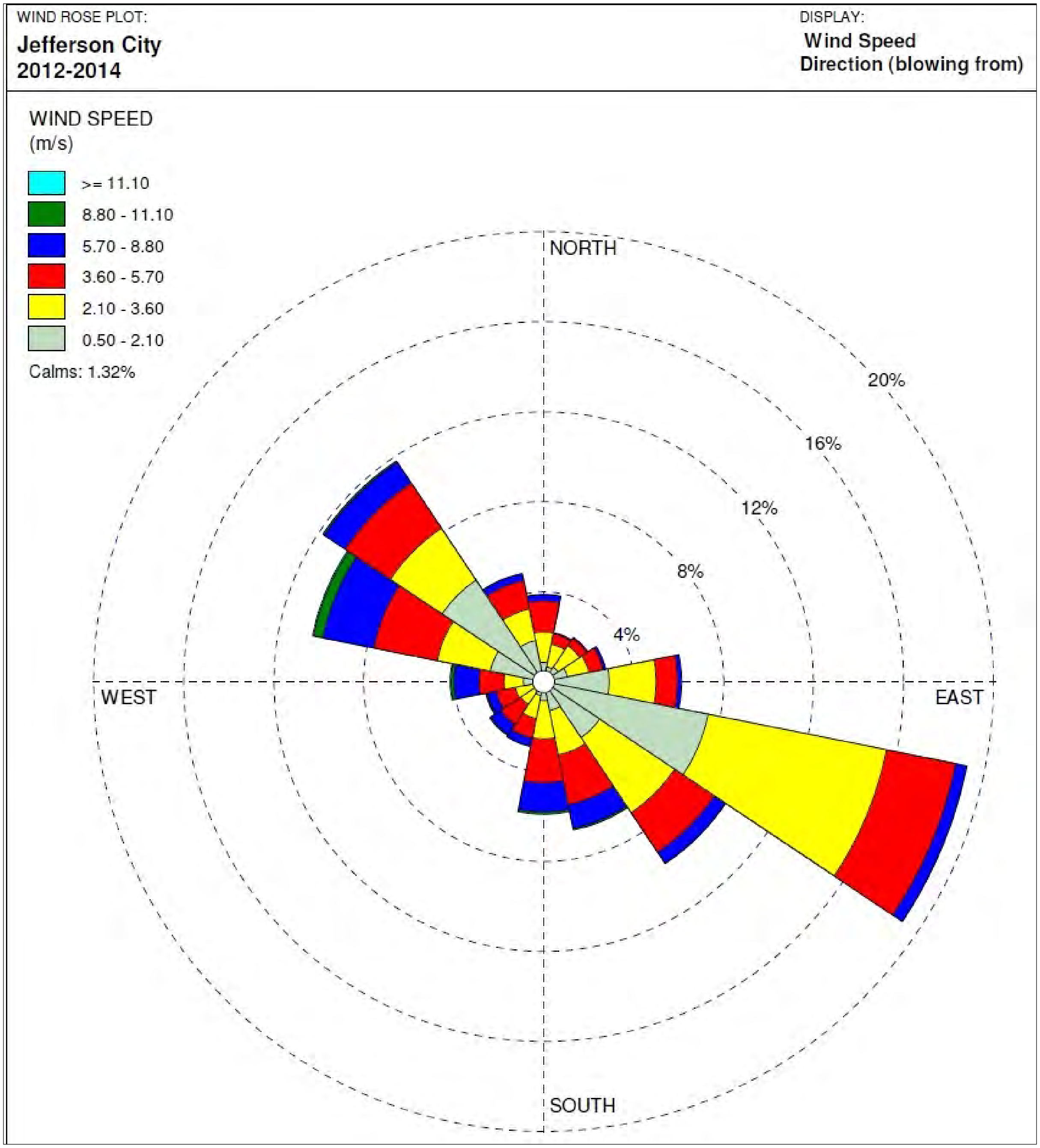
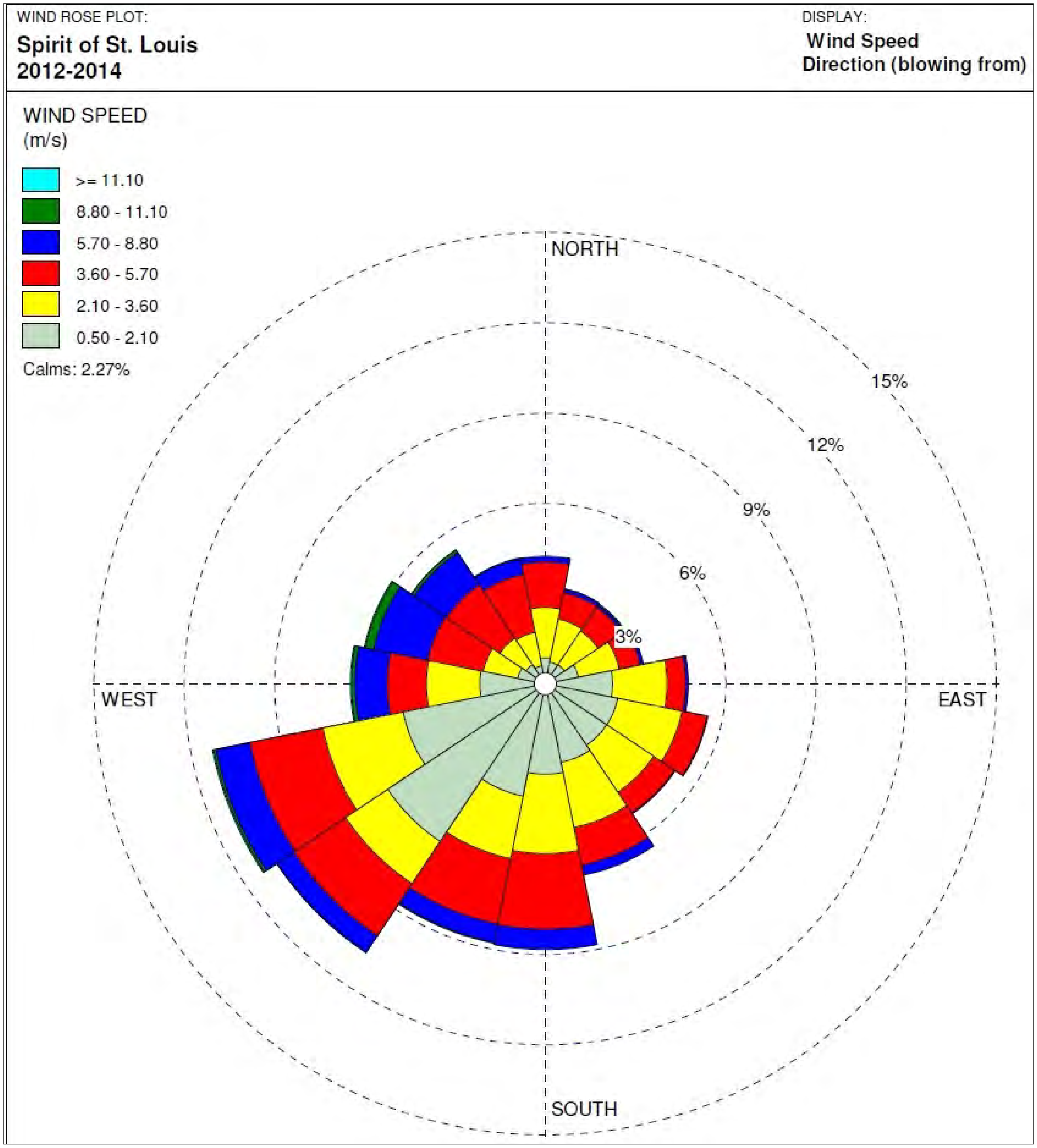


Figure 3-5: Spirit of St. Louis Wind Rose (2012-2014)



4.0 AERMOD Modeling Results

The modeling results of 99th percentile peak daily 1-hour maximum concentrations averaged over the 3 years modeled are presented in Table 4-1. The modeling was conducted with the EPA default option and beta ADJ_U* with LOWWIND3 options. The concentration isopleths for the ADJ_U* and LOWWIND3 options are plotted in Figure 4-1. Peak impacts from Labadie Energy Center occur in about 2 kilometers to the northwest, near the NW monitor installed in 2015.

An analysis of the AERMOD output in a debugging mode indicates that the meteorological and plume conditions associated with the controlling modeled impacts are due to a penetrated plume in convective conditions with a low mixing height. This feature and the tendency of AERMOD to over-predict in these cases are described in a presentation[8] delivered at EPA's 11th Modeling Conference. The presentation documents that the over-prediction tendency of AERMOD in these conditions can range up to 50%, which is generally consistent with the 10-40% uncertainty noted by Appendix W for modeling predictions in general. An over-prediction tendency of up to 50% applied to the results presented in Table 4-1 would show attainment of the NAAQS for both modeling approaches summarized in the table.

This modeling analysis, especially with the EPA-proposed improvements to AERMOD version 15181, supports the designation of the area in the vicinity of the Labadie Energy Center as being either attainment or unclassifiable for the 1-hour SO_2 NAAQS.

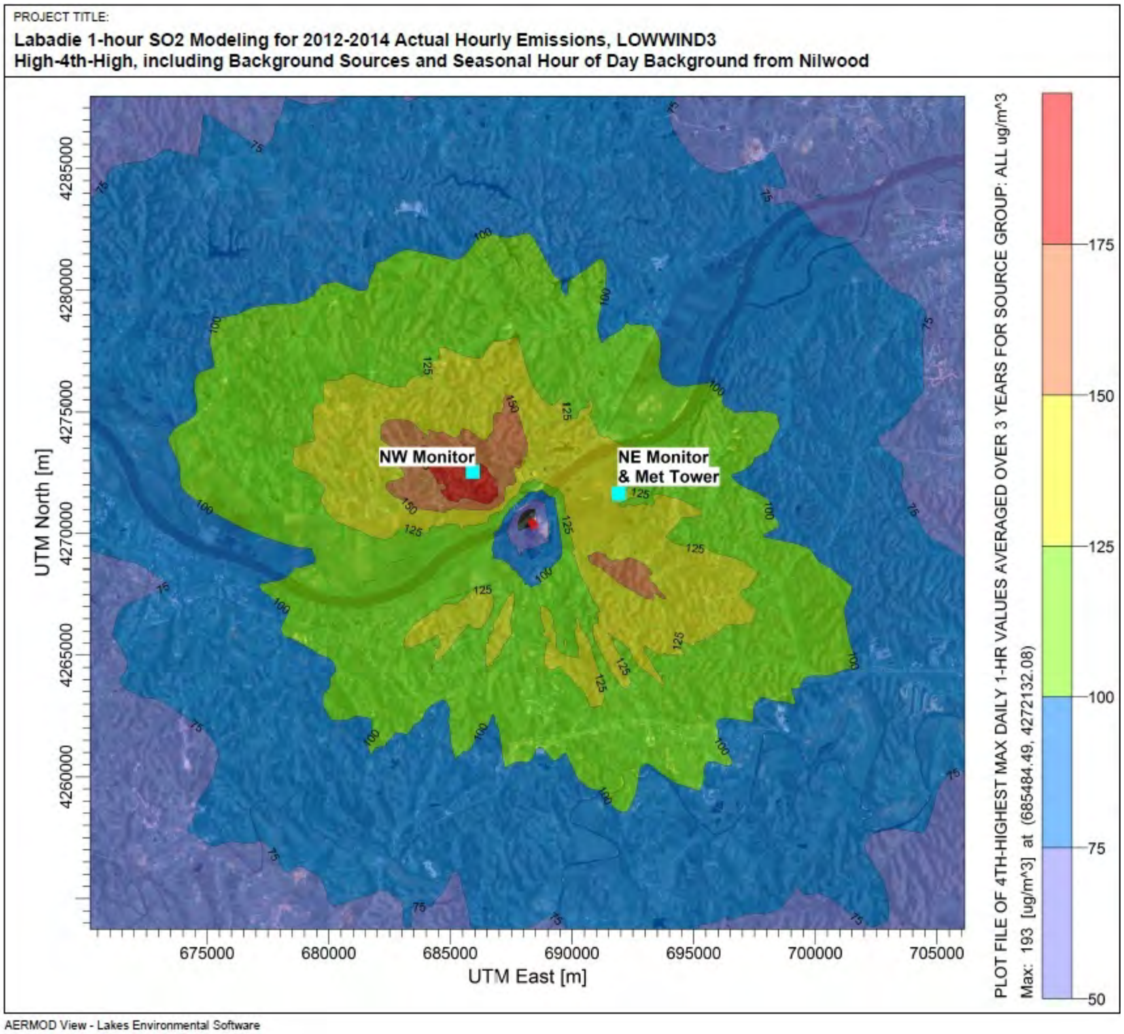
Table 4-1: AERMOD Modeled Design SO_2 Concentration Results

AERMOD Modeling Options	Labadie Concentration ($\mu g/m^3$)	Ambient Background Concentration from Nilwood ($\mu g/m^3$)	Modeled Design Concentration (2012-2014) with Seasonal Hourly Background from Nilwood ($\mu g/m^3$) (1)	NAAQS ($\mu g/m^3$)
Current Default (overall design conc.)	0.0	7.85	282.9(2)	196.5
Current Default (Labadie-caused design conc.)	212.30	20.64	232.9	196.5
ADJ_U* and LOWWIND3	172.36	20.64	193.0	196.5

(1) The "design concentration" is the 99th percentile peak daily 1-hour maximum concentration, averaged over the 3 years.
(2) This localized peak concentration near the D.B. West background source may be due to a conservative manner in which the stack source is characterized by MDNR.

[8] http://www.epa.gov/ttn/scram/11thmodconf/presentations/2-4_Penetrated_Plume_Issues.pdf.

Figure 4-1: 99th percentile 3-year average 1-hour SO_2 Concentration Isopleths with ADJ_U* and LOWWIND3 Options



Appendix A

Alternative Model Justification for Low Wind Speed Options (AERMET ADJ_U* and AERMOD LOWWIND3, Version 15181)

Alternative Model Justification for Low Wind Speed Beta Options:

AERMET and AERMOD

Appendix W, Section 3.2.2 provides an approach for approval of an alternative model to determine whether it is more appropriate for this modeling application. The principle sources involve tall stack buoyant releases.

EPA indicates that for this purpose, an alternative refined model may be used provided that:

1. The model has received a scientific peer review;
2. The model can be demonstrated to be applicable to the problem on a theoretical basis;
3. The data bases which are necessary to perform the analysis are available and adequate;
4. Appropriate performance evaluations of the model have shown that the model is not biased toward underestimates; and
5. A protocol on methods and procedures to be followed has been established.

These five points are discussed below.

The model selected for this modeling application is the EPA-proposed updates to the AERMOD modeling system version 15181, including the AERMET ADJ_U* option, combined with the AERMOD LOWWIND3 option. EPA has indicated support for these changes in the Appendix W proposal and in the Roger Brode presentation made at the 11th Modeling Conference on August 12, 2015 (see presentation at http://www.epa.gov/ttn/scram/11thmodconf/presentations/1-5_Proposed_Updates_AERMOD_System.pdf).

1. The model has received a scientific peer review

The AERMET changes reference a Boundary-Layer Meteorology peer-reviewed paper[1] that is the source of the AERMET formulation for changes in the friction velocity computation for low wind speeds. The combination of the AERMET changes and the AERMOD changes (version 14134 LOWWIND2, similar to version 15181 LOWWIND3) has been evaluated and the study[2] will be published in a forthcoming issue of the Journal of the Air & Waste Management Association (JAWMA). The manuscript associated with the JAWMA article is provided in Appendix B. A supplemental evaluation exercise with AERMET/AERMOD version 15181 is provided in Appendix C that shows consistent evaluation results (with a slight improvement) for the proposed AERMOD modeling application.

2. The model can be demonstrated to be applicable to the problem on a theoretical basis.

There is no theoretical limitation to the application of the AERMET and AERMOD low wind changes – they are generally applicable. The current default algorithm in AERMET has been demonstrated to be

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[1] Qian, W., and A. Venkatram. Performance of Steady-State Dispersion Models Under Low Wind-Speed Conditions. Boundary-Layer Meteorology 138:475–491. (2011)

[2] Paine, R., Samani, O., Kaplan, M. Knipping, E., and Kumar, N. Evaluation of Low Wind Modeling Approaches for Two Tall-Stack Databases. Pending publication (as of August, 2015) in the Journal of Air & Waste Management Association.

faulty and needs to be replaced by the ADJ_U* approach. The improvements due to the LOWWIND3 algorithm are demonstrated with the low wind model evaluations reported by the presentations[3] at the 11th EPA modeling conference

3. The data bases which are necessary to perform the analysis are available and adequate.

Routine meteorological databases that are already available are sufficient for exercising this low wind options. There are no special database requirements for the use of these options.

4. Appropriate performance evaluations of the model have shown that the model is not biased toward underestimates.

The studies cited above by EPA and AECOM provide this demonstration.

5. A protocol on methods and procedures to be followed has been established.

This report documents the methods and procedures to be followed.

[3] http://www.epa.gov/ttn/scram/11thmodconf/presentations/1-5_Proposed_Updates_AERMOD_System.pdf and http://www.epa.gov/ttn/scram/11thmodconf/presentations/2-3_Low_Wind_Speed_Evaluation_Study.pdf.

Appendix B

Evaluation of Low Wind Modeling Approaches for Two Tall-Stack Databases

Journal of the Air & Waste Management Association
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/uawm20

Evaluation of Low Wind Modeling Approaches for Two Tall-Stack Databases

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Evaluation of Low Wind Modeling Approaches for Two Tall-Stack Databases

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Abstract

The performance of the AERMOD air dispersion model under low wind speed conditions, especially for applications with only one level of meteorological data and no direct turbulence measurements or vertical temperature gradient observations, is the focus of this study. The analysis documented in this paper addresses evaluations for low wind conditions involving tall stack releases for which multiple years of concurrent emissions, meteorological data, and monitoring data are available.

AERMOD was tested on two field study databases involving several SO_2 monitors and hourly emissions data that had sub-hourly meteorological data (e.g., 10-minute averages) available using several technical options: default mode, with various low wind speed beta options, and

using the available sub-hourly meteorological data. These field study databases included: 1) Mercer County, a North Dakota database featuring five SO_2 monitors within 10 kilometers of the Dakota Gasification Company's plant and the Antelope Valley Station power plant in an area of both flat and elevated terrain, and 2) a flat-terrain setting database with four SO_2 monitors within 6 kilometers of the Gibson Generating Station in southwest Indiana. Both sites featured regionally representative 10-meter meteorological databases, with no significant terrain obstacles between the meteorological site and the emission sources.

The low wind beta options show improvement in model performance helping to reduce some of the over-prediction biases currently present in AERMOD when run with regulatory default options. The overall findings with the low wind speed testing on these tall stack field study databases indicate that AERMOD low wind speed options have a minor effect for flat terrain locations, but can have a significant effect for elevated terrain locations. The performance of AERMOD using low wind speed options leads to improved consistency of meteorological conditions associated with the highest observed and predicted concentration events. The available sub-hourly modeling results using the Sub-Hourly AERMOD Run Procedure (SHARP) are relatively unbiased and show that this alternative approach should be seriously considered to address situations dominated by low-wind meander conditions.

Implications

AERMOD was evaluated with two tall stack databases (in North Dakota and Indiana) in areas of both flat and elevated terrain. AERMOD cases included the regulatory default mode, low wind speed beta options, and use of the Sub-Hourly AERMOD Run Procedure (SHARP). The low wind beta options show improvement in model performance (especially in higher terrain areas), helping to reduce some of the over-prediction biases currently present in regulatory default AERMOD. The SHARP results are relatively unbiased and show that this approach should be seriously considered to address situations dominated by low-wind meander conditions.

Introduction

During low wind speed (LWS) conditions, the dispersion of pollutants is limited by diminished fresh air dilution. Both monitoring observations and dispersion modeling results of this study indicate that high ground-level concentrations can occur in these conditions. Wind speeds less than 2 m/sec are generally considered to be "low", with steady-state modeling assumptions compromised at these low speeds (Pasquill et al., 1983). Pasquill and Van der Hoven (1976) recognized that for such low wind speeds, a plume is unlikely to have any definable travel. Wilson et al. (1976) considered this wind speed (2 m/sec) as the upper limit for conducting tracer experiments in low wind speed conditions.

Anfossi et al. (2005) noted that in LWS conditions, dispersion is characterized by meandering horizontal wind oscillations. They reported that as the wind speed decreases, the standard deviation of the wind direction increases, making it more difficult to define a mean plume direction. Sagendorf and Dickson (1974) and Wilson et al. (1976) found that under LWS conditions, horizontal diffusion was enhanced because of this meander and the resulting ground-level concentrations could be much lower than that predicted by steady-state Gaussian plume models that did not account for the meander effect.

A parameter that is used as part of the computation of the horizontal plume spreading in the United States Environmental Protection Agency's (EPA) preferred model, AERMOD (Cimorelli et al., 2005), is the standard deviation of the crosswind component, σ_v, which can be parameterized as being proportional to the friction velocity, u_* (Smedman, 1988; Mahrt, 1998). These investigators found that there was an elevated minimum value of σ_v that was attributed to meandering. While at higher wind speeds, small-scale turbulence is the main source of variance, lateral meandering motions appear to exist in all conditions. Hanna (1990) found that σ_v maintains a minimum value of about 0.5 m/sec even as the wind speed approaches zero. Chowdhury et al. (2014) noted that a minimum σ_v of 0.5 m/s is a part of the formulation for the SCICHEM model.

Anfossi (2005) noted that meandering exists under all meteorological conditions regardless of the stability or wind speed, and this phenomenon sets a lower limit for the horizontal wind component variances as noted by Hanna (1990) over all types of terrain.

An alternative method to address wind meander was attempted by Sagendorf and Dickson (1974), who used a Gaussian model, but divided each computation period into sub-hourly (2-minute) time intervals and then combined the results to determine the total hourly concentration. This approach directly addresses the wind meander during the course of an hour by using the sub-hourly wind direction for each period modeled. As we discuss below, this approach has some appeal because it attempts to use direct wind measurements to account for sub-hourly wind meander. However, the sub-hourly time interval must not be so small as to distort the basis of the horizontal plume dispersion formulation in the dispersion model (e.g., AERMOD). Since the horizontal dispersion shape function for stable conditions in AERMOD is formulated with parameterizations derived from the 10-minute release and sampling times of the Prairie Grass experiment (Barad,1958), it is appropriate to consider a minimum sub-hourly duration of 10 minutes for such modeling using AERMOD. The Prairie Grass formulation that is part of AERMOD may also result in an underestimate of the lateral plume spread shape function in some cases, as reported by Irwin (2014) for Kincaid SF_6 releases. From analyses of hourly samples of SF_6 taken at Kincaid (a tall stack source), Irwin determined that the lateral dispersion simulated by AERMOD could underestimate the lateral dispersion (by 60%) for near-stable conditions (conditions for which the lateral dispersion formulation that was fitted to the Project Prairie Grass data could affect results).

It is clear from the discussion above that the simulation of pollutant dispersion in LWS conditions is challenging. In the United States, the use of steady-state plume models before the introduction of AERMOD in 2005 was done with the following rule implemented by EPA: "when used in steady-state Gaussian plume models, measured site-specific wind speeds of less than 1 m/sec but higher than the response threshold of the instrument should be input as 1 m/sec" (EPA, 2004).

With EPA's implementation of a new model, AERMOD, in 2005 (EPA, 2005), input wind speeds lower than 1 m/sec were allowed due to the use of a meander algorithm that was designed to account for the LWS effects As noted in the AERMOD formulation document (EPA, 2004), "AERMOD accounts for meander by interpolating between two concentration limits: the coherent plume limit (which assumes that the wind direction is distributed about a well-defined mean direction with variations due solely to lateral turbulence) and the random plume limit, (which assumes an equal probability of any wind direction)."

A key aspect of this interpolation is the assignment of a time scale (= 24 hours) at which mean wind information at the source is no longer correlated with the location of plume material at a downwind receptor (EPA, 2004). The assumption of a full diurnal cycle relating to this time scale tends to minimize the weighting of the random plume component relative to the coherent plume component for 1-hour time travel. The resulting weighting preference for the coherent plume can lead to a heavy reliance on the coherent plume, ineffective consideration of plume meander, and a total concentration overprediction.

For conditions in which the plume is emitted aloft into a stable layer or in areas of inhomogenous terrain, it would be expected the decoupling of the stable boundary layer relative to the surface layer could significantly shorten this time scale. These effects are discussed by Brett and Tuller (1991), where they note that lower wind autocorrelations occur in areas with a variety of roughness and terrain effects. Perez et al. (2004) noted that the autocorrelation is reduced in areas with terrain and in any terrain setting with increasing height in stable conditions when decoupling of vertical motions would result in a "loss of memory" of surface conditions. Therefore, the study reported in this paper has reviewed the treatment of AERMOD in low wind conditions for field data involving terrain effects in stable conditions as well as for flat terrain conditions, for which convective (daytime) conditions are typically associated with peak modeled predictions.

The computation of the AERMOD coherent plume dispersion and the relative weighting of the coherent and random plumes in stable conditions are strongly related to the magnitude of σ_v, which is directly proportional to the magnitude of the friction velocity. Therefore, the formulation of the friction velocity calculation and the specification of a minimum σ_v value were also considered in this paper. The friction velocity also affects the internally-calculated vertical temperature gradient, which affects plume rise and plume-terrain interactions, which are especially important in elevated terrain situations.

Qian and Venkatram (2011) discuss the challenges of LWS conditions in which the time scale of wind meandering is large, and the horizontal concentration distribution can be non-Gaussian. It is also quite possible that wind instrumentation cannot adequately detect the turbulence levels that would be useful for modeling dispersion. They also noted that an analysis of data from the Cardington tower indicates that Monin-Obukhov similarity theory underestimates the surface friction velocity at low wind speeds. This finding was also noted by Paine et al. (2010) in an independent investigation of Cardington data as well as data from two other research-grade databases. Both Qian and Venkatram and Paine et al. proposed similar adjustments to the calculation of the surface friction velocity by AERMET, the meteorological processor for AERMOD. EPA incorporated the Qian and Venkatram suggested approach as a “beta option” in AERMOD in late 2012 (EPA, 2012). The same version of AERMOD also introduced low wind modeling options affecting the minimum value of σ_v and the weighting of the meander component that were used in the Test Cases 2-4 described below.

AERMOD's handling of low wind speed conditions, especially for applications with only one level of meteorological data and no direct turbulence measurements or vertical temperature gradient observations, is the focus of this study. Previous evaluations of AERMOD for low wind speed conditions (e.g., Paine et al., 2010) have emphasized low-level tracer release studies conducted in the 1970s and have utilized results of researchers such as Luhar and Rayner (2009). The focus of the study reported here is a further evaluation of AERMOD, but focusing upon tall-stack field databases. One of these databases was previously evaluated (Kaplan et al., 2012) with AERMOD Version 12345, featuring a database in Mercer County, North Dakota. This database features five SO_2 monitors in the vicinity of the Dakota Gasification Company's plant and the Antelope Valley Station power plant in an area of both flat and elevated terrain. In addition to the Mercer County, ND database, this study considers an additional field database for the Gibson Generating Station tall stack in flat terrain in southwest Indiana.

EPA released AERMOD version 14134 with enhanced low wind model features that can be applied in more than one combination. There is one low wind option (beta u_*) applicable to the meteorological pre-processor, AERMET, affecting the friction velocity calculation, and a variety of options available for the dispersion model, AERMOD, that focus upon the minimum σ_v specification. These beta options have the potential to reduce the over-prediction biases currently present in AERMOD when run for neutral to stable conditions with regulatory default options (EPA, 2014 a,b). These new low wind options in AERMET and AERMOD currently require additional justification for each application in order to be considered for use in the United States. While EPA has conducted evaluations on low-level, non-buoyant studies with the AERMET and AERMOD low wind speed beta options, they have not conducted any new evaluations on tall stack releases (U.S. EPA, 2014 a, b). One of the purposes of this study was to augment the evaluation experiences for the low wind model approaches for a variety of settings for tall stack releases.

This study also made use of the availability of sub-hourly meteorological observations to evaluate another modeling approach. This approach employs AERMOD with sub-hourly meteorological data and is known as the "Sub-Hourly AERMOD Run Procedure" or SHARP (EPRI, 2013). Like the procedure developed by Sagendorf and Dickson as described above, SHARP merely subdivides each hour's meteorology (e.g., into six 10-minute periods) and AERMOD is run multiple times with the meteorological input data (e.g., minutes 1-10, 11-20, etc.) treated as "hourly" averages for each run. Then, the results of these runs are combined (averaged). In our SHARP runs, we did not employ any observed turbulence data as input. This alternative modeling approach (our Test Case 5 as discussed below) has been compared to the standard hourly AERMOD modeling approach for default and low wind modeling options (Test Cases 1-4 described below, using hourly averaged meteorological data) to determine whether it should be further considered as a viable technique. This study provides a discussion of the various low wind speed modeling options and the field study databases that were tested, as well as the modeling results.

Modeling Options and Databases for Testing

Five AERMET/AERMOD model configurations were tested for the two field study databases, as listed below. All model applications used one wind level, a minimum wind speed of 0.5 m/sec, and also used hourly average meteorological data with the exception of SHARP applications. As noted above, Test Cases 1-4 used options available in the current AERMOD code. The selections for Test Cases 1-4 exercised these low wind speed options over a range of reasonable choices extended from no low wind enhancements to a full treatment that incorporates the Qian and Venkatram (2011) u_* recommendations as well as the Hanna (1990) and Chowdhury (2014) minimum σ_v recommendations (0.5 m/sec). Test Case 5 used sub-hourly meteorological data processed with AERMET using the beta u_* option for SHARP applications. We discuss later in this document our recommendations for SHARP modeling without the AERMOD meander component included.

Test Case 1: AERMET and AERMOD in default mode.

Test Case 2: Low wind beta option for AERMET and default options for AERMOD (minimum σ_v value of 0.2 m/sec).

Test Case 3: Low wind beta option for AERMET and the LOWWIND2 option for AERMOD (minimum σ_v value of 0.3 m/sec).

Test Case 4: Low wind beta option for AERMET and the LOWWIND2 option for AERMOD (minimum σ_v value of 0.5 m/sec).

Test Case 5: Low wind beta option for AERMET and AERMOD run in sub-hourly mode (SHARP) with beta u*option.

The databases that were selected for the low wind model evaluation are listed in Table 1 and described below. They were selected due to the following attributes:

- They feature multiple years of hourly SO_2 monitoring at several sites.

- Emissions are dominated by tall stack sources that are available from continuous emission monitors.

- They include sub-hourly meteorological data so that the SHARP modeling approach could be tested as well.

- There is representative meteorological data from a single-level station typical of (or obtained from) airport-type data.

Table 1 here.

1) Mercer County, North Dakota

An available 4-year period of 2007-2010 was used for the Mercer County, ND database with five SO_2 monitors within 10 km of two nearby emission facilities (Antelope Valley and Dakota Gasification Company), site-specific meteorological data at the DGC#12 site (10-m level data in a low-cut grassy field in the location shown in Figure 1), and hourly emissions data from 15 point sources. The terrain in the area is rolling and features three of the monitors (Beulah, DGC#16, and especially DGC#17) being above or close to stack top for some of the nearby emission sources; see Figure 2 for more close-up terrain details. Figure 1 shows a layout of the sources, monitors, and the meteorological station. Tables 2 and 3 provide details about the emission sources and the monitors. Although this modeling application employed sources as far away as 50 km, the proximity of the monitors to the two nearby emission facilities meant that emissions from those facilities dominated the impacts. However, to avoid criticism from reviewers that other regional sources that should have been modeled were omitted, other regional lignite-fired power plants were included in the modeling.

2) Gibson Generating Station, Indiana

An available 3-year period of 2008-2010 was used for the Gibson Generating Station in southwest Indiana with four SO_2 monitors within 6 km of the plant, airport hourly meteorological data (from Evansville, Indiana 1-minute data, located about 40 km SSE of the plant), and hourly emissions data from one electrical generating station (Gibson). The terrain in the area is quite flat and the stacks are tall. Figure 3 depicts the locations of the emission source and the four SO_2 monitors. Although the plant had an on-site meteorological tower, EPA (EPA, 2013a) noted that the tower's location next to a large lake resulted in non-representative boundary-layer conditions for the area, and that the use of airport data would be preferred. Tables 2 and 3 provide details about the emission sources and the monitors. Due to the fact that there are no major SO_2 sources within at least 30 km of Gibson, we modeled emissions from only that plant.

Figure 1 here.

Figure 2 here.

Figure 3 here.

Meteorological Data Processing

For the North Dakota and Gibson database evaluations, the hourly surface meteorological data were processed with AERMET, the meteorological preprocessor for AERMOD. The boundary layer parameters were developed according to the guidance provided by EPA in the current AERMOD Implementation Guide (EPA, 2009). For the first modeling evaluation option, Test Case 1, AERMET was run using the default options. For the other four model evaluation options, Test Case 2 to 5, AERMET was run with the beta u_* low wind speed option.

North Dakota Meteorological Processing

Four years (2007-2010) of the 10-meter meteorological data collected at the DGC#12 monitoring station (located about 7 km SSE of the central emission sources) were processed with AERMET. The data measured at this monitoring station were wind direction, wind speed, and temperature. Hourly cloud cover data from the Dickinson Theodore Roosevelt Regional Airport, North Dakota (KDIK) ASOS station (85 km to the SW) were used in conjunction with the monitoring station data. Upper air data were obtained from the Bismarck Airport, North Dakota (KBIS; about 100 km to the SE), twice-daily soundings.

In addition, the sub-hourly (10-minute average) 10-meter meteorological data collected at the DGC#12 monitoring station were also processed with AERMET. AERMET was set up to read six 10-minute average files with the tower data and output six 10-minute average surface and profile files for use in SHARP. SHARP then used the sub-hourly output of AERMET to calculate hourly modeled concentrations, without changing the internal computations of AERMOD. The SHARP user's manual (EPRI, 2013) provides detailed instructions on processing sub-hourly meteorological data and executing SHARP.

Gibson Meteorological Processing

Three years (2008-2010) of hourly surface data from the Evansville Airport, Indiana (KEVV) ASOS station (about 40 km SSE of Gibson) were used in conjunction with the twice-daily soundings upper air data from the Lincoln Airport, Illinois (KILX, about 240 km NW of Gibson). The 10-minute sub-hourly data for SHARP were generated from the 1-minute meteorological data collected at Evansville Airport.

Emission Source Characteristics

Table 2 summarizes the stack parameters and locations of the modeled sources for the North Dakota and Gibson databases. Actual hourly emission rates, stack temperatures, and stack gas exit velocities were used for both databases.

Table 2 here.

Model Runs and Processing

For each evaluation database, the candidate model configurations were run with hourly emission rates provided by the plant operators. In the case of rapidly-varying emissions (startup and shutdown), the hourly averages may average intermittent conditions occurring during the course of the hour. Actual stack heights were used, along with building dimensions used as input to the models tested. Receptors were placed only at the location of each monitor to match the number of observed and predicted concentrations.

The monitor (receptor) locations and elevations are listed in Table 3. For the North Dakota database, the DGC#17 monitor is located in the most elevated terrain of all monitors. The monitors for the Gibson database were located at elevations at or near stack base, with stack heights ranging from 152 to 189 meters.

Table 3 here.

Tolerance Range for Modeling Results

One issue to be aware of regarding SO_2 monitored observations is that they can exhibit over- or under-prediction tendencies up to 10% and still be acceptable. This is related to the tolerance in the EPA procedures (EPA, 2013b) associated with quality control checks and span checks of ambient measurements. Therefore, even ignoring uncertainties in model input parameters and other contributions (e.g., model science errors and random variations) that can also lead to modeling uncertainties, just the uncertainty in measurements indicate that modeled-to-monitored ratios between 0.9 and 1.1 can be considered as "unbiased". In the discussion below, we consider model performance to be "relatively unbiased" if its predicted model to monitor ratio is between 0.75 and 1.25.

Model Evaluation Metrics

The model evaluation employed metrics that address three basic areas, as described below.

1) 1-hour SO_2 NAAQS Design Concentration

An operational metric that is tied to the form of the 1-hour SO_2 NAAQS is the "design concentration" (99th percentile of the peak daily 1-hour maximum values). This tabulated statistic was developed for each modeled case and for each individual monitor for each database evaluated.

2) Quantile-Quantile Plots

Operational performance of models for predicting compliance with air quality regulations, especially those involving a peak or near-peak value at some unspecified time and location, can be assessed with quantile-quantile (Q-Q) plots (Chambers et al., 1983), which are widely used in AERMOD evaluations. Q-Q plots are created by independently ranking (from largest to smallest) the predicted and the observed concentrations from a set of predictions initially paired in time and space. A robust model would have all points on the diagonal (45-degree) line. Such plots are useful for answering the question, "Over a period of time evaluated, does the distribution of the model predictions match those of observations?" Therefore, the Q-Q plot instead of the scatterplot is a pragmatic procedure for demonstrating model performance of applied models, and it is widely used by EPA (e.g., Perry et al. 2005). Venkatram et al. (2001)

support the use of Q-Q plots for evaluating regulatory models. Several Q-Q plots are included in this paper in the discussion provided below.

3) Meteorological Conditions Associated with Peak Observed vs. Modeled Concentrations

Lists of the meteorological conditions and hours/dates of the top several predictions and observations provide an indication as to whether these conditions are consistent between the model and monitoring data. For example, if the peak observed concentrations generally occur during daytime hours, we would expect that a well-performing model would indicate that the peak predictions are during the daytime as well. Another meteorological variable of interest is the wind speed magnitudes associated with observations and predictions. It would be expected, for example, that if the wind speeds associated with peak observations are low, then the modeled peak predicted hours would have the same characteristics. A brief qualitative summary of this analysis is included in this paper and supplemental files contain the tables of the top 25 (unpaired) predictions and observations for all monitors and cases tested.

North Dakota Database Model Evaluation Procedures and Results

AERMOD was run for five test cases to compute the 1-hour daily maximum 99th percentile averaged over four years at the five ambient monitoring locations listed in Table 3.

A regional background of 10 $\mu g/m^3$ was added to the AERMOD modeled predictions. The 1-hour 99th percentile background concentration was computed from the 2007-2010 lowest hourly monitored concentration among the five monitors so as to avoid double-counting impacts from sources already being modeled.

The ratios of the modeled (including the background of 10 μg/m^3) to monitored design concentrations are summarized in Table 4 and graphically plotted in Figure 4 and are generally greater than 1. (Note that the background concentration is a small fraction of the total concentration, as shown in Table 4). For the monitors in simple terrain (DGC#12, DGC#14, and Beulah), the evaluation results are similar for both the default and beta options and are within 5-30% of the monitored concentrations depending on the model option. The evaluation result for the monitor in the highest terrain (DGC#17) shows that the ratio of modeled to monitored concentration is more than 2, but when this location is modeled with the AERMET and AERMOD low wind beta option, the ratio is significantly better, at less than 1.3. It is noteworthy that the modeling results for inclusion of just the beta u_* option are virtually identical to the default AERMET run for the simple terrain monitors, but the differences are significant for the higher terrain monitor (DGC#17). For all of the monitors, it is evident that further reductions of AERMOD's over-predictions occur as the minimum σ_v in AERMOD is increased from 0.3 to 0.5 m/sec. For a minimum σ_v of 0.5 m/sec at all the monitors, AERMOD is shown to be conservative with respect to the design concentration.

The Q-Q plots of the ranked top fifty daily maximum 1-hour SO_2 concentrations for predictions and observations are shown in Figure 5. For the convenience of the reader, a vertical dashed line is included in each Q-Q plot to indicate the observed design concentration. In general, the Q-Q plots indicate the following:

- For all of the monitors, to the left of the design concentration line, the AERMOD hourly runs all show ranked predictions at or higher than observations. To the right of the design concentration line, the ranked modeled values for specific test cases and monitors are lower than the ranked observed levels, and the slope of the line formed by the plotted points is less than the slope of the 1:1 line. For model performance goals that would need to predict well for the peak concentrations (rather than the 99th percentile statistic), this area of the Q-Q plots would be of greater importance.

- The very highest observed value (if indeed valid) is not matched by any of the models for all of the monitors, but since the focus is on the 99th percentile form of the United States ambient standard for SO_2, this area of model performance is not important for this application.

- The ranked SHARP modeling results are lower than all of the hourly AERMOD runs, but at the design concentration level, they are, on average, relatively unbiased over all of the monitors. The AERMOD runs for SHARP included the meander component, which probably contributed to the small under-predictions noted for SHARP. In future modeling, we would advise users of SHARP to employ the AERMOD LOWWIND1 option to disable the meander component.

Table 4 here.

Figure 4 here.

Figure 5 here.

Gibson Generating Station Database Model Evaluation Procedures and Results

AERMOD was run for five test cases for this database as well in order to compute the 1-hour daily maximum 99th percentile averaged over three years at the four ambient monitoring locations listed in Table 3.

A regional background of 18 μg/m^3 was added to the AERMOD modeled predictions. The 1-hour 99th percentile background concentration was computed from the 2008-2010 lowest hourly monitored concentration among the four monitors so as to avoid impacts from sources being modeled.

The ratio of the modeled (including the background of 18 μg/m^3) to monitored concentrations is summarized in Table 5 and graphically plotted in Figure 6 and are generally greater than 1.0. (Note that the background concentration is a small fraction of the total concentration, as shown in Table 5.) Figure 6 shows that AERMOD with hourly averaged meteorological data over-predicts by about 40-50% at Mt. Carmel and Gibson Tower monitors and by about 9-31% at East Mt. Carmel and Shrodt monitors. As expected (due to dominance of impacts with convective conditions), the AERMOD results do not vary much with the various low wind speed options in this flat terrain setting. AERMOD with sub-hourly meteorological data (SHARP) has the best (least biased predicted-to-observed ratio of design concentrations) performance among the five cases modeled. Over the four monitors, the range of predicted-to-observed ratios for SHARP is a narrow one, ranging from a slight under-prediction by 2% to an over-prediction by 14%.

The Q-Q plots of the ranked top fifty daily maximum 1-hour SO_2 concentrations for predictions and observations are shown in Figure 7. It is clear from these plots that the SHARP results parallel and are closer to the 1:1 line for a larger portion of the concentration range than any other model tested. In general, AERMOD modeling with hourly data exhibits an over-prediction tendency at all of the monitors for the peak ranked concentrations at most of the monitors. The AERMOD/SHARP models predicted lower relative to observations at the East Mt. Carmel monitor for the very highest values, but match well for the 99th percentile peak daily 1-hour maximum statistic.

Table 5 here.

Figure 6 here.

Figure 7 here.

Evaluation Results Discussion

The modeling results for these tall stack releases are sensitive to the source local setting and proximity to complex terrain. In general, for tall stacks in simple terrain, the peak ground-level impacts mostly occur in daytime convective conditions. For settings with a mixture of simple and complex terrain, the peak impacts for the higher terrain are observed to occur during both daytime and nighttime conditions, while AERMOD tends to favor stable conditions only without low wind speed enhancements. Exceptions to this "rule of thumb" can occur for stacks with aerodynamic building downwash effects. In that case, high observed and modeled predictions are likely to occur during high wind events during all times of day.

The significance of the changes in model performance for tall stacks (using a 90th percentile confidence interval) was independently tested for a similar model evaluation conducted for Eastman Chemical Company (Paine et al., 2013; Szembek et al., 2013), using a modification of the Model Evaluation Methodology (MEM) software that computed estimates of the hourly stability class (Strimaitis et al., 1993). That study indicated that relative to a perfect model, a model that over-predicted or under-predicted by less than about 50% would likely show a performance level that was not significantly different. For a larger difference in bias, one could expect a statistically significant difference in model performance. This finding has been adopted as an indicator of the significance of different modeling results for this study.

A review of the North Dakota ratios of monitored to modeled values in Figure 4 generally indicates that for DGC#12, DGC#14, and Beulah, the model differences were not significantly different. For DGC#16, it could be concluded that the SHARP results were significantly better than the default AERMOD results, but other AERMOD variations were not significantly better. For the high terrain monitor, DGC#17, is it evident that all of the model options departing from default were significantly better than the default option, especially the SHARP approach.

For the Gibson monitors (see Figure 6), the model variations did not result in significantly different performance except for the Gibson Tower (SHARP vs. the hourly modes of running AERMOD).

General conclusions from the review of meteorological conditions associated with the top observed concentrations at the North Dakota monitors , provided in the supplemental file called "North Dakota Meteorological Conditions Resulting in Top 25 Concentrations", are as follows:

- A few peak observed concentrations occur at night with light winds. Majority of observations for the DGC#12 monitor are mostly daytime conditions with moderate to strong winds.

- Peak observations for the DGC#14 and Beulah monitors are mostly daytime conditions with a large range of wind speeds. Once again, a minority of the peak concentrations occur at night with a large range of wind speeds.

- Peak observed concentrations for the DGC#16 and DGC#17 monitors occur at night with light winds. Majority of observations are mixed between daytime and nighttime conditions with a large range of wind speeds for both. The DGC#17 monitor is located in elevated terrain.

The conclusions from the review of the meteorological conditions associated with peak AERMOD or SHARP predictions are as follows:

- AERMOD hourly peak predictions for the DGC#12 and Beulah monitors are consistently during the daytime with light to moderate wind speeds and limited mixing heights. This is a commonly observed situation that is further discussed below.

- There are similar AERMOD results for DGC#14, except that there are more periods with high winds and higher mixing heights.

- The AERMOD results for DGC#16 still features mostly daytime hours, but with more high wind conditions.

- The default AERMOD results for DGC#17 are distinctly different from the other monitors, with most hours featuring stable, light winds. There are also a few daytime hours of high predictions with low winds and low mixing heights. This pattern changes substantially with the beta u_* options employed, when the majority of the peak prediction hours are daytime periods with light to moderate wind speeds. This pattern is more consistent with the peak observed concentration conditions.

- The SHARP peak predictions at the North Dakota monitors were also mostly associated with daytime hours with a large range of wind speeds for all of the monitors.

The North Dakota site has some similarities due to a mixture of flat and elevated terrain to the Eastman Chemical Company model evaluation study in Kingsport, Tennessee (this site features three coal-fired boiler houses with tall stacks). In that study (Paine et al. 2013; Szembek et al., 2013), there was one monitor in elevated terrain and two monitors in flat terrain with a full year of data. Both the North Dakota and Eastman sites featured observations of the design concentration being within about 10% of the mean design concentration over all monitors. Modeling results using default options in AERMOD for both of these sites indicated a large spread of the predictions, with predictions in high terrain exceeding observations by more than a factor of 2. In contrast, the predictions in flat terrain, while higher than observations, showed a lower overprediction bias. The use of low wind speed improvements in AERMOD (beta u_* in

AERMET and an elevated minimum σ_v value) did improve model predictions for both databases.

The conclusions from the review of the meteorological conditions associated with peak observations , provided in the supplemental file called "Gibson Meteorological Conditions Resulting in Top 25 Concentrations", are as follows:

- Peak observations for the Mt. Carmel and East Mt. Carmel monitors occur during both light wind convective conditions and strong wind conditions (near neutral, both daytime and nighttime).

- Nighttime peaks that are noted at Mt. Carmel and East Mt. Carmel could be due to downwash effects with southerly winds.

- Gibson Tower and Shrodt monitors were in directions with minimal downwash effects; therefore, the peak impacts at these monitors occur with convective conditions.

- The Gibson Tower and Shrodt monitor peak observation conditions were similarly mixed for wind speeds, but they were consistently occurring during the daytime only.

AERMOD (hourly) modeling runs and SHARP runs are generally consistent with the patterns of observed conditions for Shrodt and Gibson Tower monitors. Except for downwash effects, the peak concentrations were all observed and predicted during daytime hours. There are similar AERMOD results for Mt. Carmel and East Mt. Carmel, except that there are more nighttime periods and periods with strong wind conditions.

As noted above, AERMOD tends to focus its peak predictions for tall stacks in simple terrain (those not affected by building downwash) for conditions with low mixing heights in the morning. However, a more detailed review of these conditions indicates that the high predictions are not simply due to plumes trapped within the convective mixed layer, but instead due to plumes that initially penetrate the mixing layer, but then emerge (after a short travel time) into the convective boundary layer in concentrated form with a larger-than-expected vertical spread. Tests of this condition were undertaken by Dr. Ken Rayner of the Western Australia Department of Environmental Regulation (2013), who found the same condition occurring for tall stacks in simple terrain for a field study database in his province. Rayner found that AERMOD tended to over-predict peak concentrations by a factor of about 50% at a key monitor, while with the penetrated plume removed from consideration, AERMOD would underpredict by about 30%. Therefore, the correct treatment might be a more delayed entrainment of the penetrated plume into the convective mixed layer. Rayner's basic conclusions were that:

- A plume penetrates and disperses within a 1-hour time step in AERMOD, while in the real world, dispersion of a penetrated puff may occur an hour or more later, after substantial travel time.

- A penetrated plume initially disperses via a vertical Gaussian formula, not a convective probability density function. Because penetrated puffs typically have a very small vertical dispersion, they are typically fully entrained (in AERMOD) in a single hour by a growing mixed layer, and dispersion of a fully entrained puff is via convective mixing, with relatively rapid vertical dispersion, and high ground-level concentrations.

Conclusions and Recommendations for Further Research

This study has addressed additional evaluations for low wind conditions involving tall stack releases for which multiple years of concurrent emissions, meteorological data, and monitoring data were available. The modeling cases that were the focus of this study involved applications with only one level of meteorological data and no direct turbulence measurements or vertical temperature gradient observations.

For the North Dakota evaluation, the AERMOD model over-predicted, using the design concentration as the metric for each monitor. For the relatively low elevation monitors, the results were similar for both the default and beta options and are within 5-30% of the monitored concentrations depending on the model option. The modeling result for the elevated DGC#17 monitor showed that this location is sensitive to terrain as the ratio of modeled to monitored concentration is over 2. However, when this location was modeled with the low wind beta option, the ratio was notably better, at less than 1.3. Furthermore, the low wind speed beta option changed the AERMOD's focus on peak predictions conditions from mostly nighttime to mostly daytime periods, somewhat more in line with observations. Even for a minimum σ_v as high as 0.5 m/sec, all of the AERMOD modeling results were conservative or relatively unbiased (for the design concentration). The North Dakota evaluation results for the sub-hourly (SHARP) modeling were, on average, relatively unbiased, with a predicted-to-observed design concentration ratio ranging from 0.89 to 1.2. With a 10% tolerance in the SO_2 monitored values, we find that the SHARP performance is quite good. Slightly higher SHARP predictions would be expected if AERMOD were run with the LOWWIND1 option deployed.

For the Gibson flat terrain evaluation, AERMOD with hourly averaged meteorological data over-predicted at three of the four monitors between 30-50 %, and about 10% at the fourth monitor. The AERMOD results did not vary much with the various low wind speed options in this flat terrain setting. AERMOD with sub-hourly meteorological data (SHARP) had the best (least biased predicted-to-observed ratio of design concentrations) performance among the five cases modeled. Over the four monitors, the range of predicted-to-observed ratios for SHARP was a narrow one, ranging from a slight under-prediction by 2% to an over-prediction by 14%. All other modeling options had a larger range of results.

The overall findings with the low wind speed testing on these tall stack databases indicate that:

- The AERMOD low wind speed options have a minor effect for flat terrain locations.

- The AERMOD low wind speed options have a more significant effect with AERMOD modeling for elevated terrain locations, and the use of the LOWWIND2 option with a minimum σ_v on the order of 0.5 m/sec is appropriate.

- The AERMOD sub-hourly modeling (SHARP) results are mostly in the unbiased range (modeled to observed design concentration ratios between 0.9 and 1.1) for the two databases tested with that option.

- The AERMOD low wind speed options improve the consistency of meteorological conditions associated with the highest observed and predicted concentration events.

Further analysis of the low wind speed performance of AERMOD with either the SHARP procedure or the use of the minimum σ_v specifications by other investigators is encouraged. However, SHARP can only be used if sub-hourly meteorological data is available. For Automated Surface Observing Stations (ASOS) with 1-minute data, this option is a possibility if the 1-minute data are obtained and processed.

Although the SHARP results reported in this paper are encouraging, further testing is recommended to determine the optimal sub-hourly averaging time (no less than 10 minutes is recommended) and whether other adjustments to AERMOD (e.g., total disabling of the meander option) is recommended. Another way to implement the sub-hourly information in AERMOD and to avoid the laborious method of running AERMOD several times for SHARP would be to include a distribution, or range, of the sub-hourly wind directions to AERMOD so that the meander calculations could be refined.

For most modeling applications that use hourly averages of meteorological data with no knowledge of the sub-hourly wind distribution, it appears that the best options with the current AERMOD modeling system are to implement the AERMET beta u_* improvements and to use a minimum σ_v value on the order of 0.5 m/sec/sec.

It is noteworthy that EPA has recently approved (EPA, 2015) as a site-specific model for Eastman Chemical Company the use of the AERMET beta u_* option as well as the LOWWIND2 option in AERMOD with a minimum σ_v of 0.4 m/sec. This model, which was evaluated with site-specific meteorological data and 4 SO_2 monitors operated for 1 year, performed well in flat terrain, but overpredicted in elevated terrain, where a minimum σ_v value of 0.6 m/sec actually performed better. This would result in an average value of the minimum σ_v of about 0.5 m/sec, consistent with the findings of Hanna (1990).

The concept of a minimum horizontal wind fluctuation speed on the order of about 0.5 m/sec is further supported by the existence of vertical changes (shears) in wind direction (as noted by Etling, 1990) that can result in effective horizontal shearing of a plume that is not accounted for in AERMOD. Although we did not test this concept here, the concept of vertical wind shear effects, which are more prevalent in de-coupled stable conditions than in well-mixed convective conditions suggests that it would be helpful to have a "split minimum σ_v" approach in AERMOD that enables the user to specify separate minimum σ_v values for stable and unstable conditions. This capability would, of course, be backward-compatible to the current minimum σ_v specification that applies for all stability conditions in AERMOD now.

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Table 1. Databases Selected for the Model Evaluation

	Mercer County, North Dakota	**Gibson Generating Station, Indiana**
Number of emission sources modeled	15	5
Number of SO_2 monitors	5 (one above stack top for several sources)	4 (all below stack top)
Type of terrain	Rolling	Flat
Meteorological years and data source	2007-2010 local 10-meter tower data	2008-2010 Evansville airport
Meteorological data time step	Hourly and sub-hourly	Hourly and sub-hourly

Emissions and exhaust data	Actual hourly variable emissions and velocity, fixed temperature	Actual hourly variable emissions and velocity, fixed temperature

Table 2. Source Information

Data Base	Source ID	UTM X (m)	UTM Y (m)	Base Elev. (m)	Stack Height (m)	Exit Temp (K)	Stack Dia. (m)
ND	Antelope Valley	285920	5250189	588.3	182.9	Vary	7.0
ND	Antelope Valley	285924	5250293	588.3	182.9	Vary	7.0
ND	Leland Olds	324461	5239045	518.3	106.7	Vary	5.3
ND	Leland Olds	324557	5238972	518.3	152.4	Vary	6.7
ND	Milton R Young	331870	5214952	597.4	171.9	Vary	6.2
ND	Milton R Young	331833	5214891	600.5	167.6	Vary	9.1

ND	Coyote	286875	5233589	556.9	151.8	Vary	6.4
ND	Stanton	323642	5239607	518.2	77.7	Vary	4.6
ND	Coal Creek	337120	5249480	602.0	201.2	Vary	6.7
ND	Coal Creek	337220	5249490	602.0	201.2	Vary	6.7
ND	Dakota Gasification Company	285552	5249268	588.3	119.8	Vary	7.0
ND	Dakota Gasification Company	285648	5249553	588.3	68.6	Vary	0.5
ND	Dakota Gasification Company	285850	5248600	588.3	76.2	Vary	1.0
ND	Dakota Gasification	285653	5249502	588.3	30.5	Vary	0.5

	Company						
Gibson	Gibson 1	432999	4247189	119.0	189.0	327.2	7.6
Gibson	Gibson 2	432999	4247189	119.0	189.0	327.2	7.6
Gibson	Gibson 3	432923	4247251	118.5	189.0	327.2	7.6
Gibson	Gibson 4	432886	4247340	117.9	152.4	327.2	7.2
Gibson	Gibson 5	432831	4247423	116.3	152.4	327.2	7.2

Notes: SO_2 emission rate and exit velocity vary on hourly basis for each modeled source. Exit temperature varies by hour for the ND sources, but with wet scrubbing, is fixed at 327.2 deg K.

UTM zones are 14 for North Dakota and 16 for Gibson.

Table 3. Monitor/Receptor Locations

Data base	**Monitor**	**UTM X (m)**	**UTM Y (m)**	**Monitor Elevation (m)**
ND	DGC#12	291011	5244991	593.2
ND	DGC#14	290063	5250217	604.0
ND	DGC#16	283924	5252004	629.1
ND	DGC#17[a]	279025	5253844	709.8
ND	Beulah	290823	5242062	627.1
Gibson	Mt. Carmel	432424	4250202	119.0
Gibson	East Mt. Carmel	434654	4249666	119.3
Gibson	Shrodt	427175	4247182	138.0
Gibson	Gibson Tower	434792	4246296	119.0

[a] This monitor's elevation is above stack top for several of the ND sources.

Table 4. North Dakota Ratio of Monitored to Modeled Design Concentrations*

Test Case	Monitor	Observed	Predicted	Ratio
Test Case 1 (Default AERMET, Default AERMOD)	DGC#12	91.52	109.96	1.20
	DGC#14	95.00	116.84	1.23
	DGC#16	79.58	119.94	1.51
	DGC#17	83.76	184.48	2.20
	Beulah	93.37	119.23	1.28
Test Case 2 (Beta AERMET, Default AERMOD)	DGC#12	91.52	109.96	1.20
	DGC#14	95.00	116.84	1.23
	DGC#16	79.58	119.94	1.51
	DGC#17	83.76	127.93	1.53
	Beulah	93.37	119.23	1.28
Test Case 3 (Beta AERMET, AERMOD with LOWWIND2 σ_v = 0.3 m/sec)	DGC#12	91.52	103.14	1.13
	DGC#14	95.00	110.17	1.16
	DGC#16	79.58	111.74	1.40
	DGC#17	83.76	108.69	1.30
	Beulah	93.37	106.05	1.14

Test Case 4 (Beta AERMET, AERMOD with LOWWIND2 σ_v = 0.5 m/sec)	DGC#12	91.52	95.86	1.05
	DGC#14	95.00	100.50	1.06
	DGC#16	79.58	106.65	1.34
	DGC#17	83.76	101.84	1.22
	Beulah	93.37	92.32	0.99
Test Case 5 (SHARP)	DGC#12	91.52	82.18	0.90
	DGC#14	95.00	84.24	0.89
	DGC#16	79.58	95.47	1.20
	DGC#17	83.76	88.60	1.06
	Beulah	93.37	86.98	0.93
*Design Concentration: 99th percentile peak daily 1-hour maximum, averaged over the years				

Table 5. Gibson Ratio of Monitored to Modeled Design Concentrations*

Test Case	Monitor	Observed	Predicted	Ratio
Test Case 1 (Default AERMET, Default AERMOD)	Mt. Carmel	197.25	278.45	1.41
	East Mt. Carmel	206.89	230.74	1.12
	Shrodt	148.16	189.63	1.28
	Gibson Tower	127.12	193.71	1.52
Test Case 2 (Beta AERMET, Default AERMOD)	Mt. Carmel	197.25	287.16	1.46
	East Mt. Carmel	206.89	229.22	1.11
	Shrodt	148.16	189.63	1.28
	Gibson Tower	127.12	193.71	1.52
Test Case 3 (Beta AERMET, AERMOD with LOWWIND2 σ_v = 0.3 m/sec)	Mt. Carmel	197.25	280.32	1.42
	East Mt. Carmel	206.89	224.65	1.09
	Shrodt	148.16	184.82	1.25
	Gibson Tower	127.12	192.22	1.51
Test Case 4 (Beta AERMET, AERMOD with LOWWIND2 σ_v = 0.5 m/sec)	Mt. Carmel	197.25	277.57	1.41
	East Mt. Carmel	206.89	224.65	1.09
	Shrodt	148.16	176.81	1.19
	Gibson Tower	127.12	192.22	1.51
Test Case 5	Mt. Carmel	197.25	225.05	1.14

(SHARP)	East Mt. Carmel	206.89	202.82	0.98
	Shrodt	148.16	136.41	0.92
	Gibson Tower	127.12	148.64	1.17
*Design Concentration: 99th percentile peak daily 1-hour maximum, averaged over the years				

Figure 1. Map of North Dakota Model Evaluation Layout

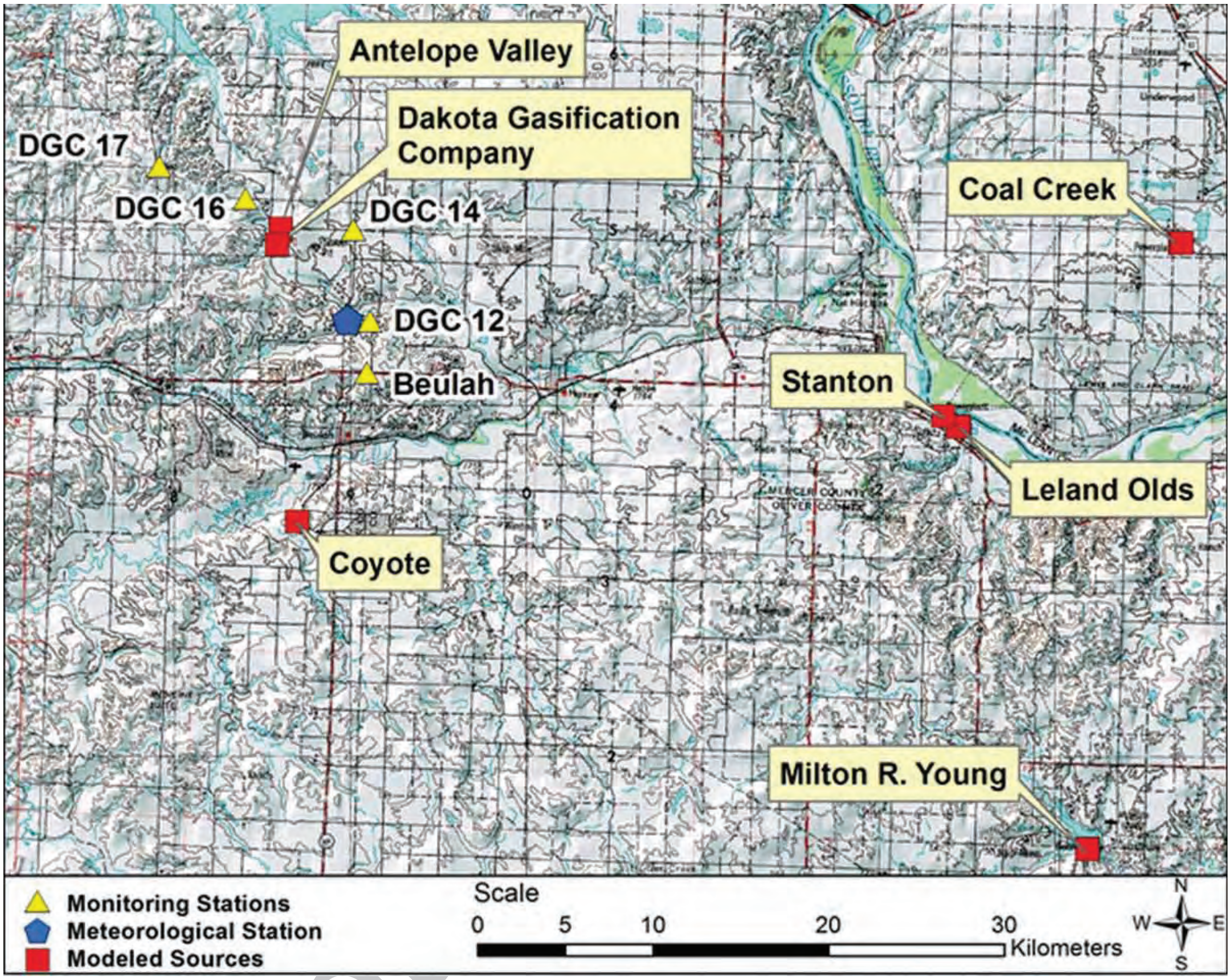


Figure 2. Terrain Around the North Dakota Monitors

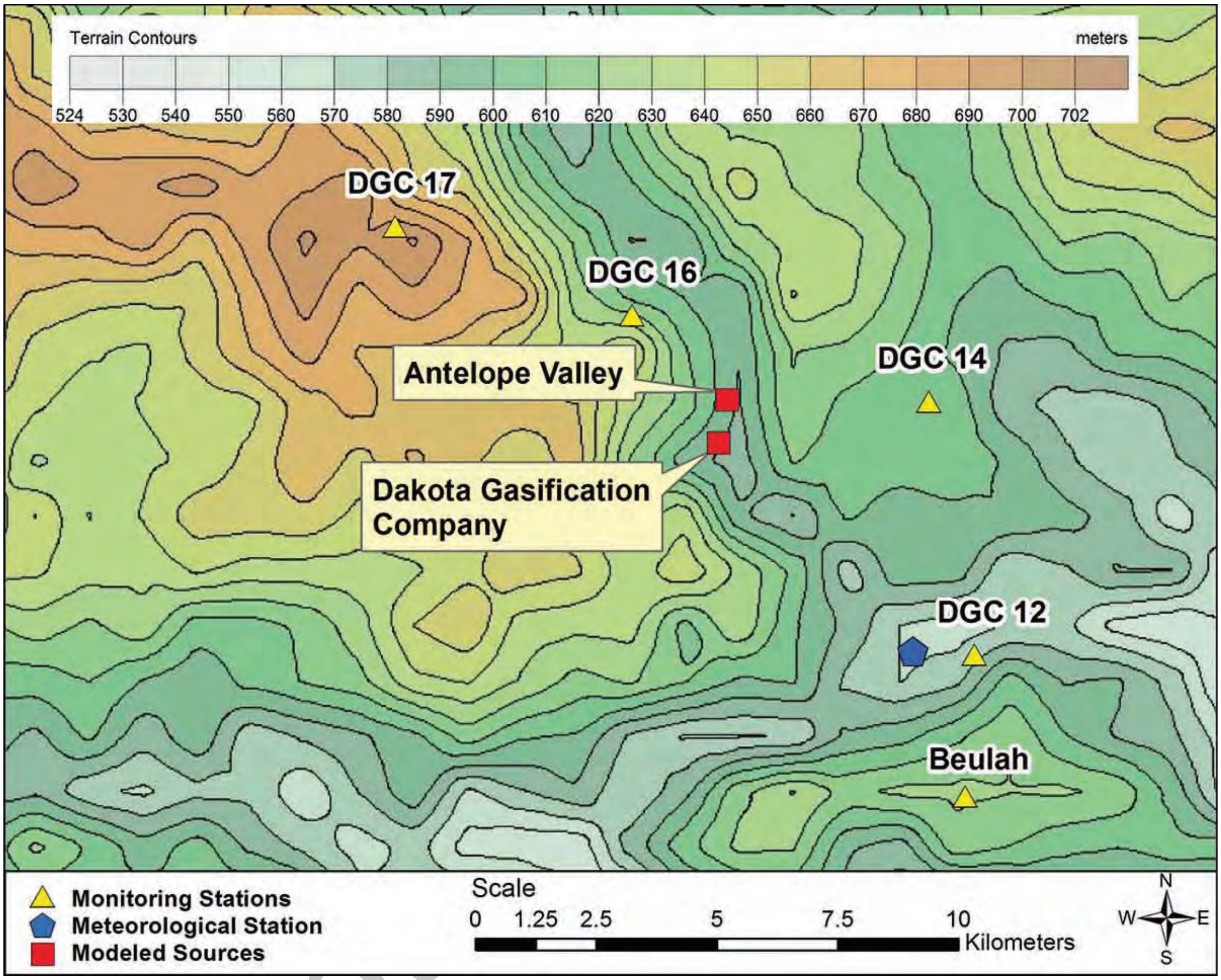


Figure 3. Map of Gibson Model Evaluation Layout

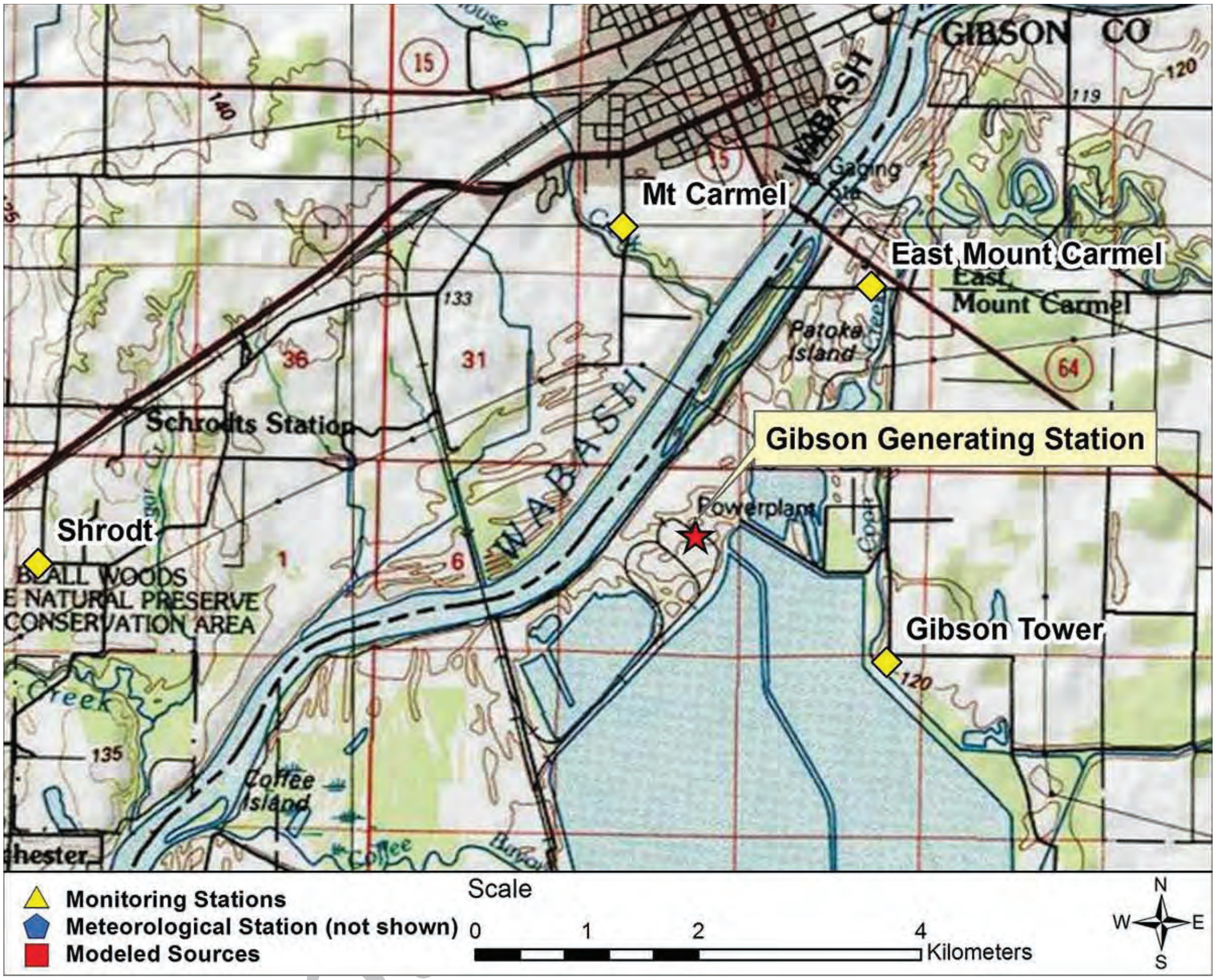


Figure 4. North Dakota Ratio of Monitored to Modeled Design Concentration Values at Specific Monitors

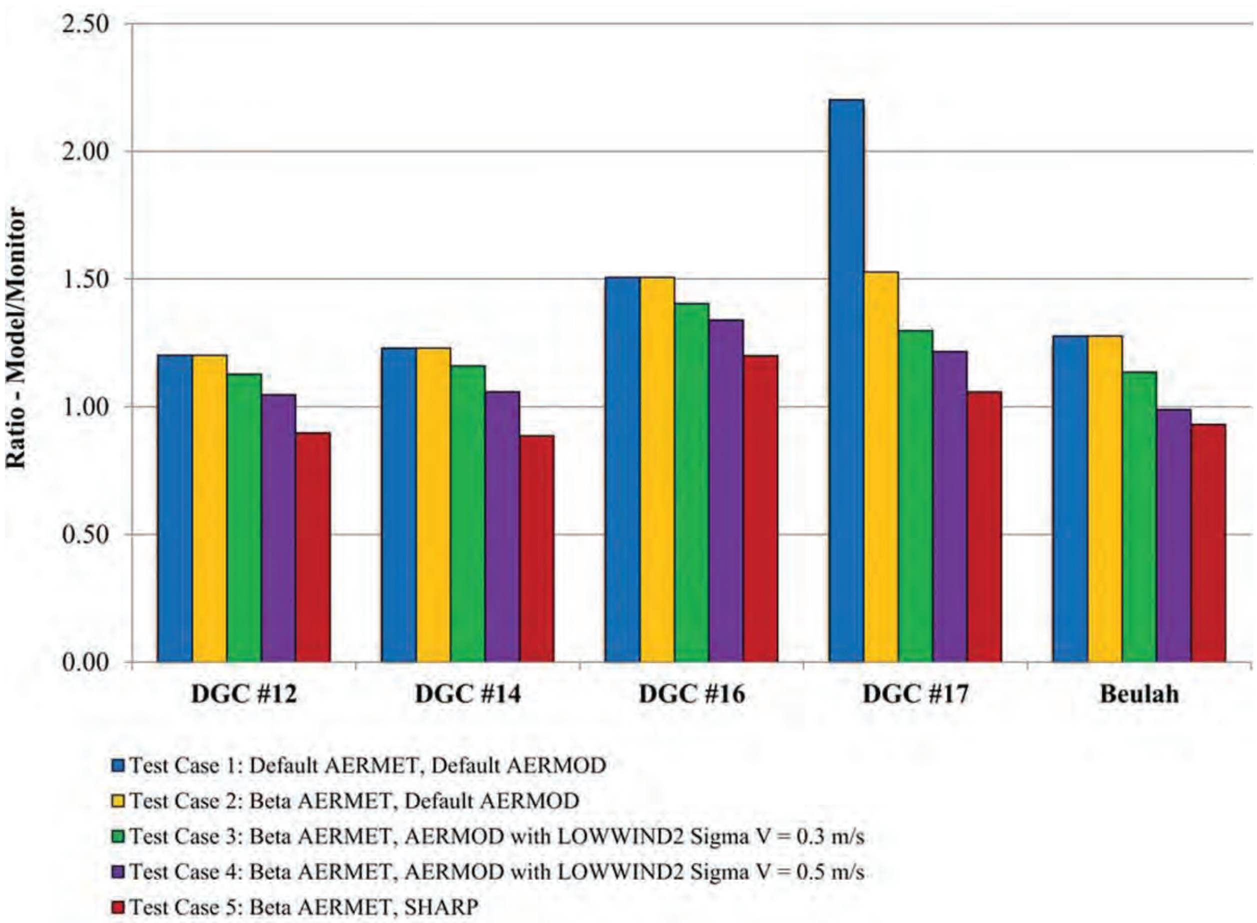


Figure 5. North Dakota Q-Q Plots: Top 50 Daily Maximum 1-hour SO_2 Concentrations. (a) DGC #12 Monitor. (b) DGC#14 Monitor. (c) DGC#16 Monitor. (d) DGC#17 Monitor. (e) Beulah Monitor

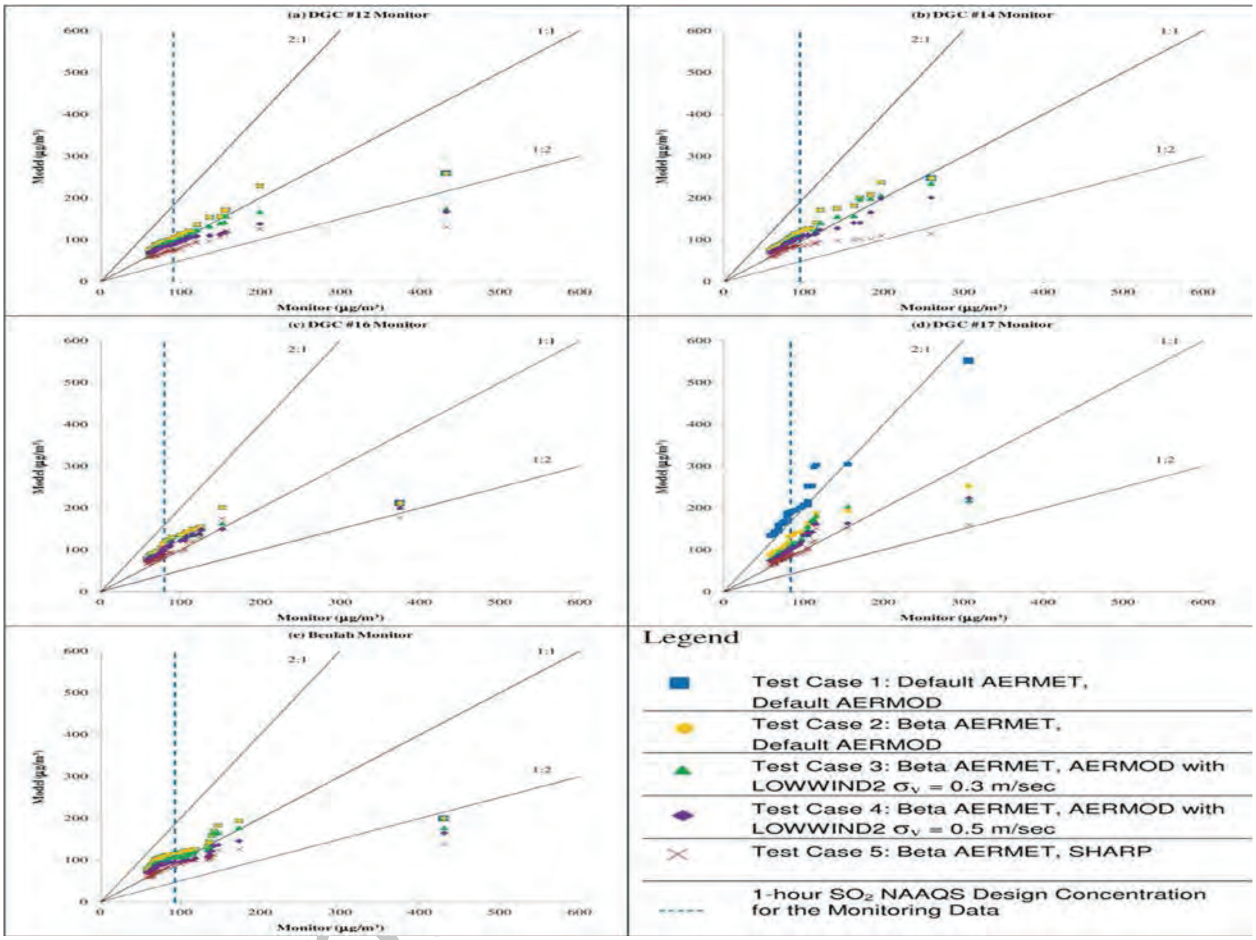


Figure 6. Gibson Ratio of Monitored to Modeled Design Concentration Values at Specific Monitors

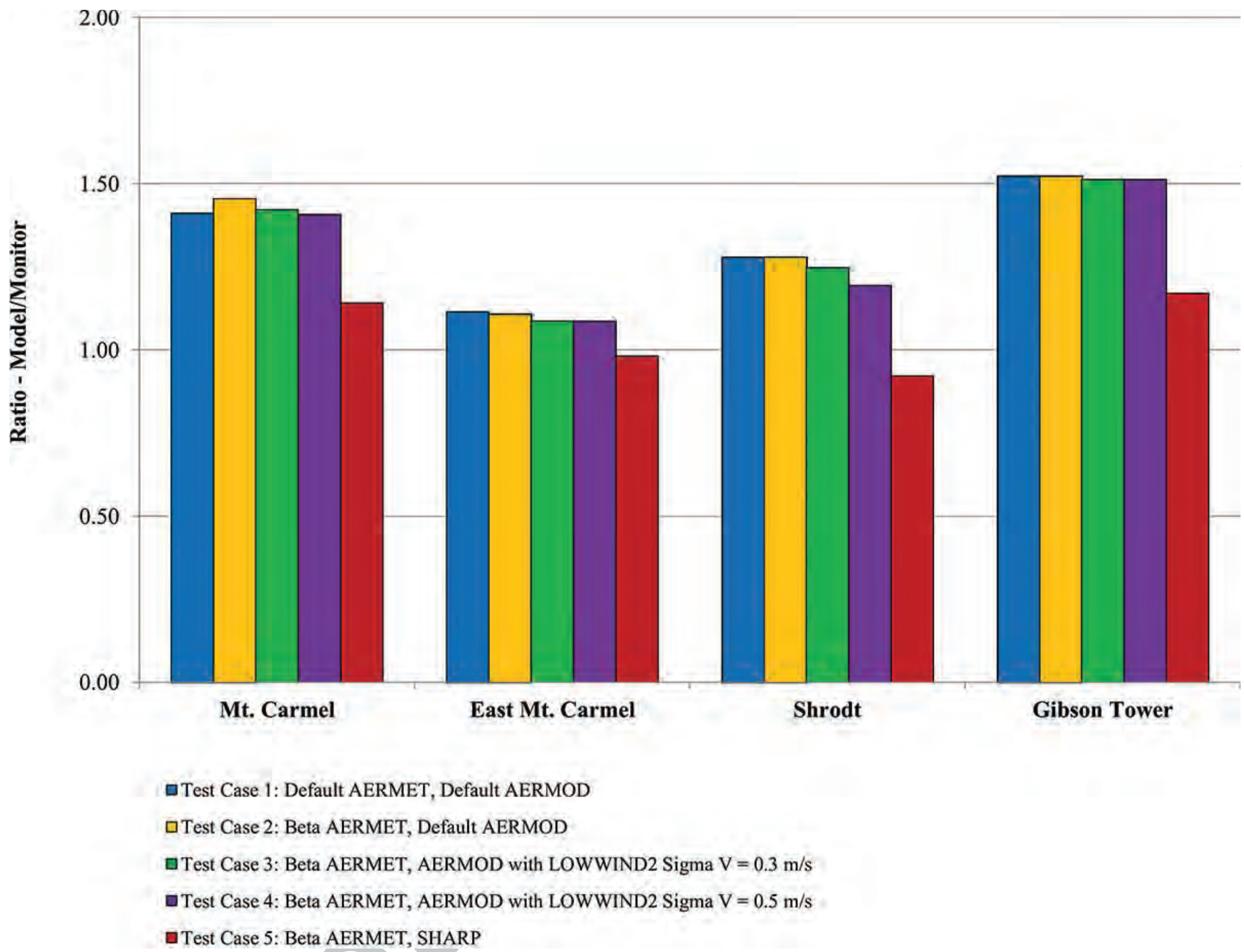
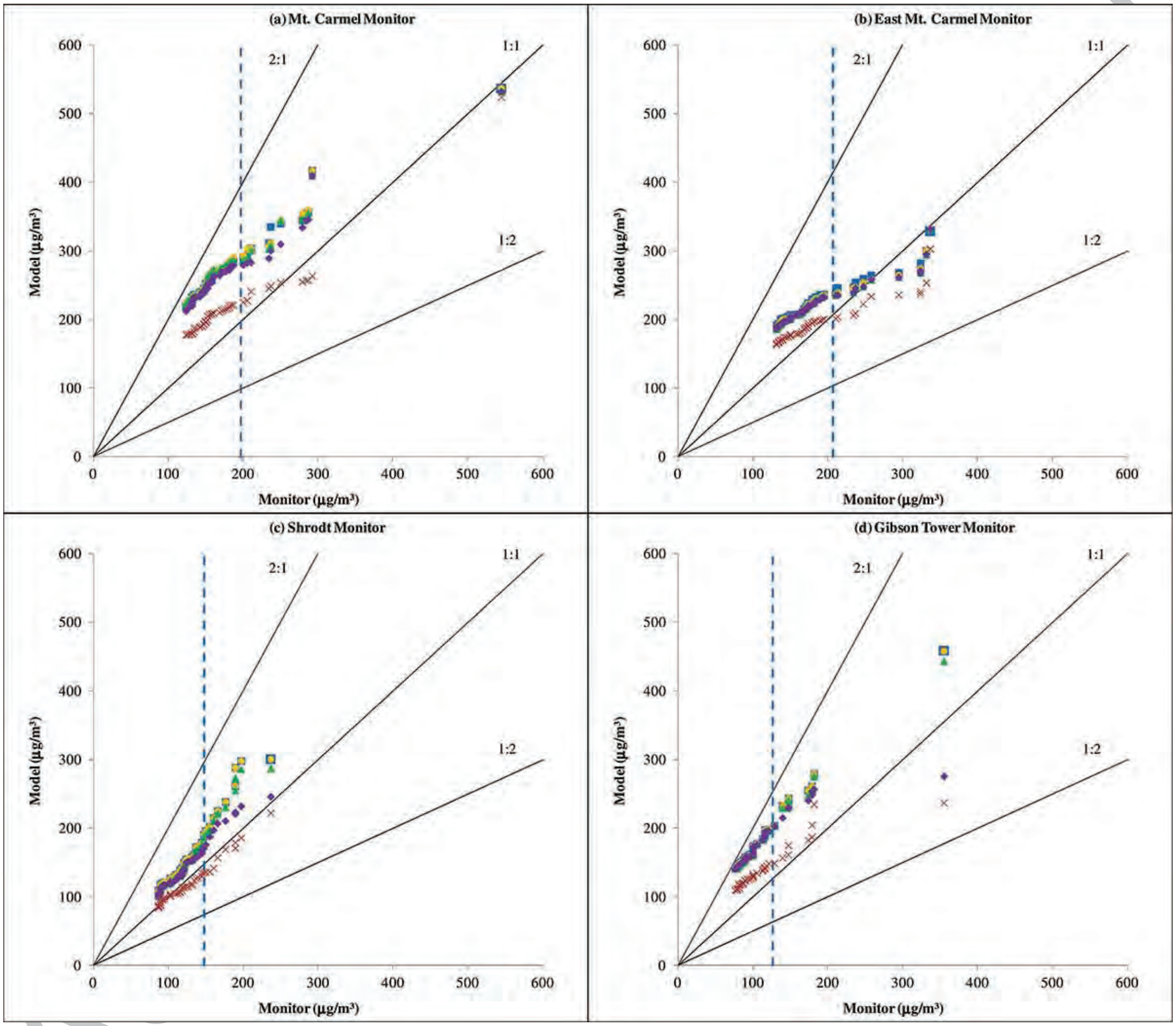


Figure 7. Gibson Q-Q Plots: Top 50 Daily Maximum 1-hour SO_2 Concentrations.

(a) Mt. Carmel Monitor. (b) East Mt. Carmel Monitor. (c) Shrodt Monitor. (d) Gibson Tower Monitor. For the legend, see Figure 5.



Appendix C

Evaluation of Low Wind Modeling Approaches for Two Tall-Stack Databases with AERMET ADJ_U* and AERMOD LOWWIND3 Options

Evaluation of Low Wind Modeling Approaches for Two Tall-Stack Databases with AERMET ADJ_U* and AERMOD LOWWIND3 Options

Olga Samani and Robert Paine, AECOM

August 22, 2015

Introduction

In a proposed rulemaking published in the July 29, 2015 Federal Register (80 FR 45340), the United States Environmental Protection Agency (EPA) released a revised version of AERMOD (15181), which replaces the previous version of AERMOD dated 14134. EPA proposed refinements to its preferred short-range model, AERMOD, involving low wind conditions. These refinements involve an adjustment to the computation of the friction velocity ("ADJ_U*") in the AERMET meteorological pre-processor and a higher minimum lateral lateral wind speed standard deviation, sigma-v (σ_v), as incorporated into the "LOWWIND3" option. The proposal indicates that "the LOWWIND3 BETA option increases the minimum value of sigma-v from 0.2 to 0.3 m/s, uses the FASTALL approach to replicate the centerline concentration accounting for horizontal meander, but utilizes an effective sigma-y and eliminates upwind dispersion".[1]

This document describes the evaluation of the combined ADJ_U* and LOWWIND3 options as recommended by EPA for incorporated as default options in AERMOD version 15181 on two previously evaluated tall-stack databases as described by Paine et al. (2015)[2]. Here we compare the model evaluation results of these new options relative to the various modeling options previously tested model options in AERMOD version 14134.

Modeling Options and Databases for Testing

The meteorological data, emissions, and receptors used in this analysis were identical to Paine et al. (2015) analysis. Two AERMET/AERMOD model configurations were tested for the two field study databases.

- AERMET and AERMOD in default mode with version 15181.
- Low wind beta option for AERMET (ADJ_U*) and the LOWWIND3 option for AERMOD (LOWWIND3 automatically sets minimum σ_v value to 0.3 m/sec) with version 15181.

The results were compared to the five AERMET/AERMOD model configurations previously tested in Paine et al. (2015) with version 13350.

- AERMET and AERMOD in default mode.

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[1] Addendum User's Guide for the AMS/EPA Regulatory Model – AERMOD http://www.epa.gov/ttn/scram/models/aermod/aermod_userguide.zip

[2] Paine, R., Samani, O., Kaplan, M. Knipping, E., and Kumar, N. Evaluation of Low Wind Modeling Approaches for Two Tall-Stack Databases. Pending publications (as of August, 2015) in the Journal of Air & Waste Management Association.

- Low wind beta option for AERMET and default options for AERMOD (minimum σ_v value of 0.2 m/sec).
- Low wind beta option for AERMET and the LOWWIND2 option for AERMOD (minimum σ_v value of 0.3 m/sec).
- Low wind beta option for AERMET and the LOWWIND2 option for AERMOD (minimum σ_v value of 0.5 m/sec).
- Low wind beta option for AERMET and AERMOD run in sub-hourly mode (SHARP).

All model applications used one wind level, a minimum wind speed of 0.5 m/sec, and also used hourly average meteorological data with the exception of SHARP applications.

The Mercer County, North Dakota and Gibson Generating Station, Indiana databases were selected for the low wind model evaluation due to the following attributes:

- They feature multiple years of hourly SO_2 monitoring at several sites.
- Emissions are dominated by tall stack sources that are available from continuous emission monitors.
- They include sub-hourly meteorological data so that the SHARP modeling approach could be tested as well.
- There is representative meteorological data from a single-level station typical of (or obtained from) airport-type data.

Model Evaluation Results

The model evaluation employed metrics that address two basic areas:

1) 1-hour SO_2 NAAQS Design Concentration averaged over the years modeled at each monitor.

An operational metric that is tied to the form of the 1-hour SO_2 NAAQS is the “design concentration” (99th percentile of the peak daily 1-hour maximum values). This tabulated statistic was developed for each modeled case and for each individual monitor for each database evaluated.

2) Quantile-Quantile Plots for each monitor.

Operational performance of models for predicting compliance with air quality regulations, especially those involving a peak or near-peak value at some unspecified time and location, can be assessed with quantile-quantile (Q-Q) plots, which are widely used in AERMOD evaluations. Q-Q plots are created by independently ranking (from largest to smallest) the predicted and the observed concentrations from a set of predictions initially paired in time and space. A robust model would have all points on the diagonal (45-degree) line.

North Dakota Database Model Evaluation Procedures and Results

AERMOD was run for the two version 15181 configurations described above to compute the 1-hour daily maximum 99th percentile averaged over four years at the five ambient monitoring locations. A regional background of 10 µg/m^3 was added to the AERMOD modeled predictions, as determined from a review of rural monitors unaffected by local sources.

The 1-hour SO_2 design concentrations and ratios of the modeled (including the background of 10 µg/m^3) to monitored design concentrations for the North Dakota evaluation database are summarized in Table 1 and graphically plotted in Figure 2. The results of the Paine et al. (2015) model evaluation analysis for the five options (version 13350) is shown here along with the results of the new evaluation with AERMOD version 15181.

The overall results indicate that the predicted-to-observed ratios are generally greater than 1.0 and AERMOD version 15181 still over-predicts even with use of the proposed ADJ_u* and the LOWWIND3 options. The low wind options show improvement relative to the default options at all monitors, especially the monitor in higher terrain (DGC #17).

As shown in Figure 1, and as expected the results for the new model with low wind options are very close to the AERMOD version 14134 model with ADJ_U* and LOWWIND2. The results of the two model versions with default options are also very close to each other.

The Q-Q plots of the ranked top fifty daily maximum 1-hour SO_2 concentrations for predictions and observations are shown in Figure 2 (a-e) for AERMOD version 15181 default and low wind options. For the convenience of the reader, a vertical dashed line is included in each Q-Q plot to indicate the observed design concentration. In general, the Q-Q plots indicate the following:

- For all of the monitors, to the left of the design concentration line, the ranked predictions are at or higher than observations.
- To the right of the design concentration line, some of the ranked modeled values are lower than the ranked observed levels (although this is not the case for DGC #17).

Gibson Generating Station Database Model Evaluation Procedures and Results

AERMOD was run for the two version 15181 configurations described above to compute the 1-hour daily maximum 99th percentile averaged over three years at the four ambient monitors. A regional background of 18 µg/m^3 was added to the AERMOD modeled predictions.

The ratio of the modeled (including the background of 18 µg/m^3) to monitored concentrations is summarized in Table 2 and graphically plotted in Figure 3, and these ratios are generally greater than 1.0. The current version of AERMOD (version 15181) run in default mode showed no changes from the previous version's default results, still having over-predictions of about 10-50%. The proposed low wind options provided modest improvements in performance relative to the default options, while still showing an over-prediction tendency at each monitor.

The Q-Q plots of the ranked top fifty daily maximum 1-hour SO_2 concentrations for predictions and observations are shown in Figure 4 (a-d). As in the case of the North Dakota evaluation results, the Gibson plots indicate the following:

- For all of the monitors, to the left of the design concentration line, the ranked predictions are at or higher than observations.
- To the right of the design concentration line, some of the ranked modeled values are lower than the ranked observed levels (although this is not the case for Shrodt or Mt. Carmel for the low wind options).

Conclusions

The model evaluation results for the new version of AERMOD (version 15181) on the two databases showed that the proposed low wind options (ADJ_U* and LOWWIND3) perform better than the default options, while still overpredicting the design concentration at each monitor in both databases. Therefore, in conjunction with other evaluations that EPA reported at the 11th modeling conference on August 12, 2015, we recommend that EPA adopt the proposed low wind options default options, and allow their use in the interim for all modeling applications.

Table 1: North Dakota Ratio of Monitored to Modeled Design Concentrations*

Model Version	Test Case	Monitor	Observed	Predicted	Ratio
13350 (previously reported results)	Default AERMET, Default AERMOD	DGC#12	91.52	109.96	1.20
		DGC#14	95.00	116.84	1.23
		DGC#16	79.58	119.94	1.51
		DGC#17	83.76	184.48	2.20
		Beulah	93.37	119.23	1.28
15181	Default AERMET, Default AERMOD	DGC#12	91.52	110.77	1.21
		DGC#14	95.00	117.51	1.24
		DGC#16	79.58	120.30	1.51
		DGC#17	83.76	184.49	2.20
		Beulah	93.37	120.31	1.29
13350 (previously reported results)	Beta AERMET, Default AERMOD	DGC#12	91.52	109.96	1.20
		DGC#14	95.00	116.84	1.23
		DGC#16	79.58	119.94	1.51
		DGC#17	83.76	127.93	1.53
		Beulah	93.37	119.23	1.28
13350 (previously reported results)	Beta AERMET, AERMOD with LOWWIND2 σ_v = 0.3 m/sec	DGC#12	91.52	103.14	1.13
		DGC#14	95.00	110.17	1.16
		DGC#16	79.58	111.74	1.40
		DGC#17	83.76	108.69	1.30
		Beulah	93.37	106.05	1.14
13350 (previously reported results)	Beta AERMET, AERMOD with LOWWIND2 σ_v = 0.5 m/sec	DGC#12	91.52	95.86	1.05
		DGC#14	95.00	100.50	1.06
		DGC#16	79.58	106.65	1.34
		DGC#17	83.76	101.84	1.22
		Beulah	93.37	92.32	0.99
15181	Beta AERMET, AERMOD with LOWWIND3	DGC#12	91.52	98.75	1.08
		DGC#14	95.00	112.09	1.18
		DGC#16	79.58	111.20	1.40
		DGC#17	83.76	108.76	1.30
		Beulah	93.37	99.54	1.07
13350 (previously reported results)	SHARP	DGC#12	91.52	82.18	0.90
		DGC#14	95.00	84.24	0.89
		DGC#16	79.58	95.47	1.20
		DGC#17	83.76	88.60	1.06
		Beulah	93.37	86.98	0.93

*Design Concentration: 99th percentile peak daily 1-hour maximum, averaged over the years modeled and monitored.

Figure 1: North Dakota Ratio of Monitored to Modeled Design Concentration Values

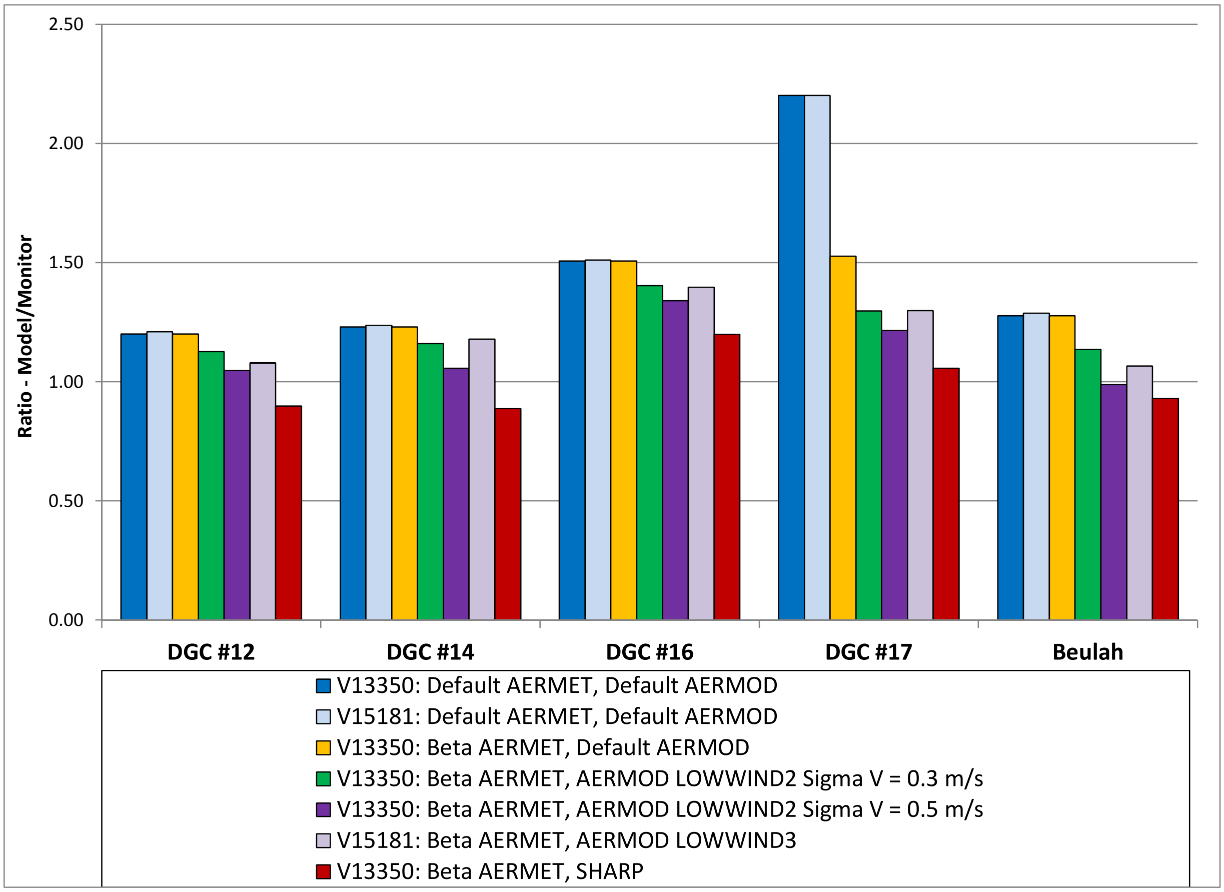
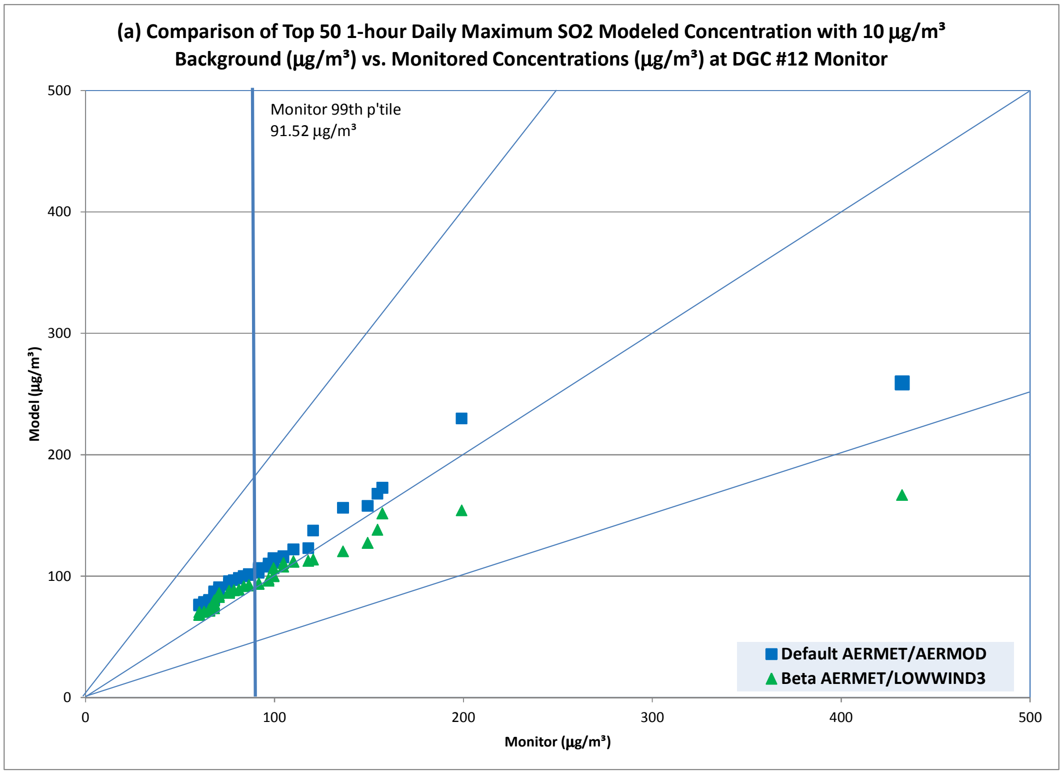
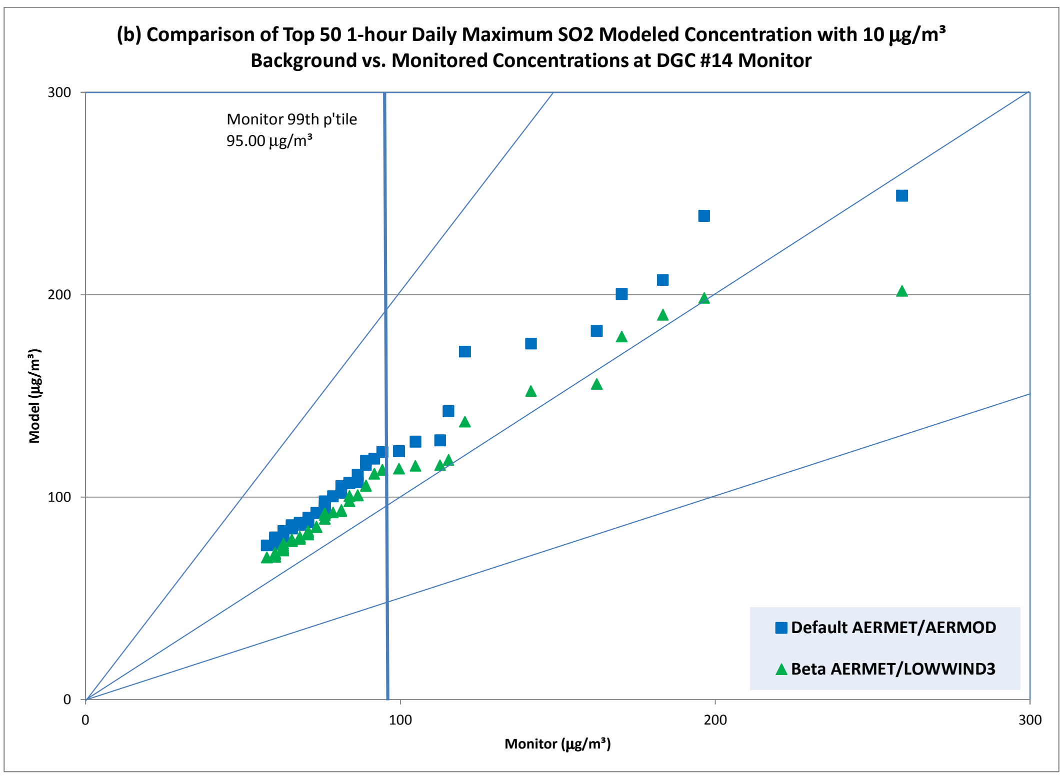
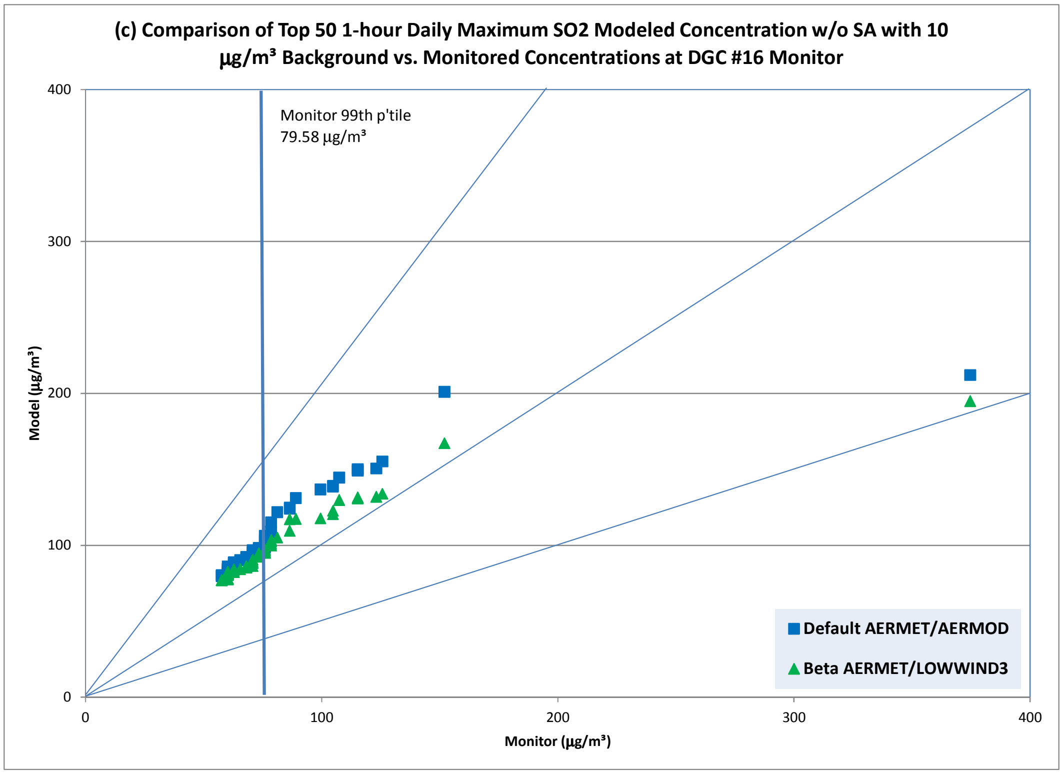
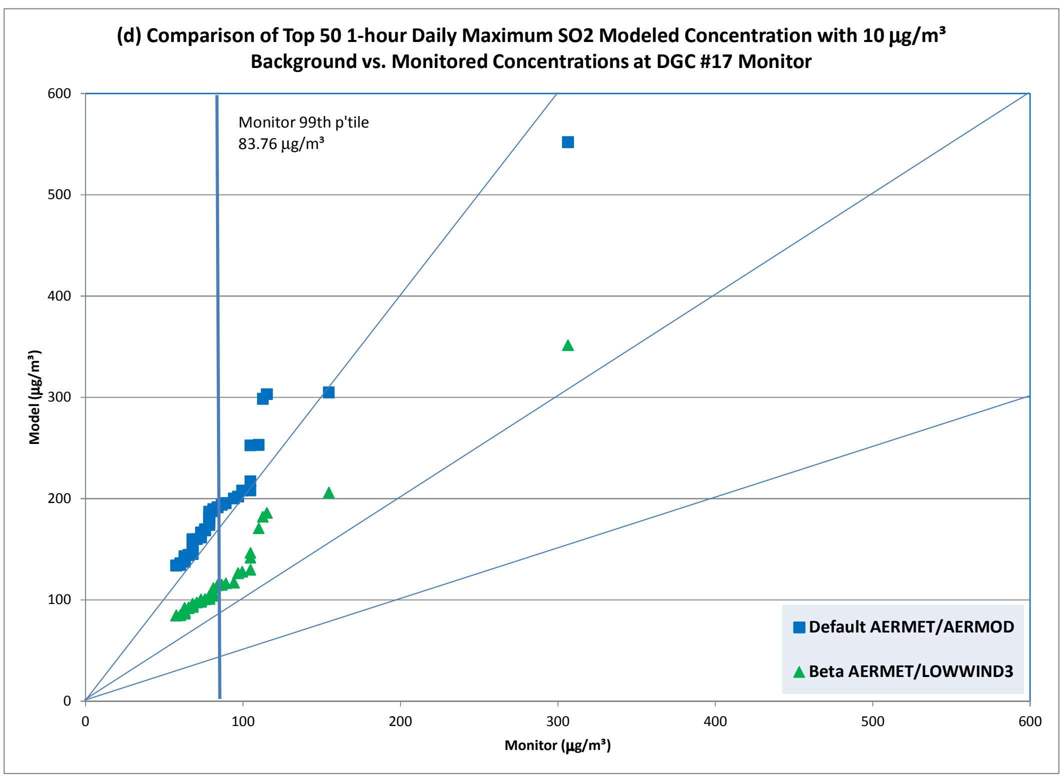


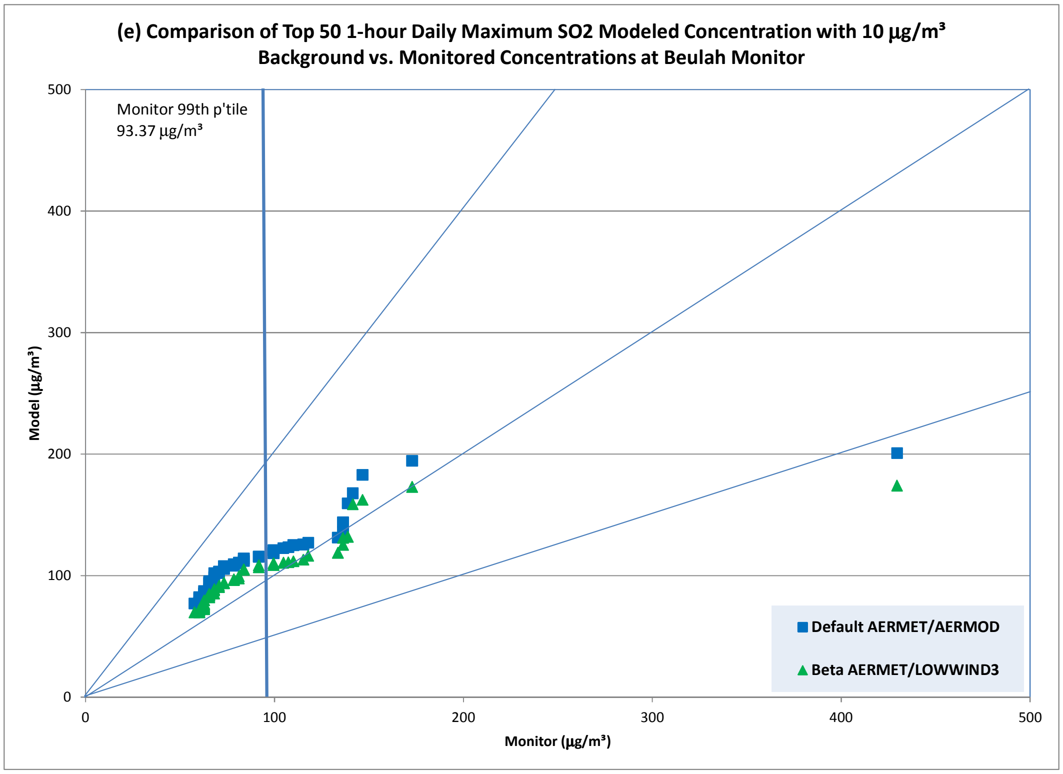
Figure 2: North Dakota Q-Q Plots: Top 50 Daily Maximum 1-hour SO_2 Concentrations. (a) DGC #12 Monitor. (b) DGC#14 Monitor. (c) DGC#16 Monitor. (d) DGC#17 Monitor. (e) Beulah Monitor






(c) Comparison of Top 50 1-hour Daily Maximum SO2 Modeled Concentration w/o SA with 10 µg/m³ Background vs. Monitored Concentrations at DGC #16 Monitor
Monitor 99th p'tile
79.58 µg/m³
Model (µg/m³)
Monitor (µg/m³)
0
100
200
300
400
Default AERMET/AERMOD
Beta AERMET/LOWWIND3


(d) Comparison of Top 50 1-hour Daily Maximum SO2 Modeled Concentration with 10 µg/m³ Background vs. Monitored Concentrations at DGC #17 Monitor
Monitor 99th p'tile
83.76 µg/m³
Model (µg/m³)
Monitor (µg/m³)
0
100
200
300
400
500
600
Default AERMET/AERMOD
Beta AERMET/LOWWIND3



(e) Comparison of Top 50 1-hour Daily Maximum SO2 Modeled Concentration with 10 µg/m³ Background vs. Monitored Concentrations at Beulah Monitor
Monitor 99th p'tile
93.37 µg/m³
Model (µg/m³)
Monitor (µg/m³)
0
100
200
300
400
500
Default AERMET/AERMOD
Beta AERMET/LOWWIND3

Table 2: Gibson Ratio of Monitored to Modeled Design Concentrations*

Model Version	Test Case	Monitor	Observed	Predicted	Ratio
13350 (previously reported results)	Default AERMET, Default AERMOD	Mt. Carmel	197.25	278.45	1.41
		East Mt.	206.89	230.74	1.12
		Shrodt	148.16	189.63	1.28
		Gibson Tower	127.12	193.71	1.52
15181	Default AERMET, Default AERMOD	Mt. Carmel	197.25	278.45	1.41
		East Mt.	206.89	230.74	1.12
		Shrodt	148.16	189.63	1.28
		Gibson Tower	127.12	193.71	1.52
13350 (previously reported results)	Beta AERMET, Default AERMOD	Mt. Carmel	197.25	287.16	1.46
		East Mt.	206.89	229.22	1.11
		Shrodt	148.16	189.63	1.28
		Gibson Tower	127.12	193.71	1.52
13350 (previously reported results)	Beta AERMET, AERMOD with LOWWIND2 σ_v = 0.3 m/sec	Mt. Carmel	197.25	280.32	1.42
		East Mt.	206.89	224.65	1.09
		Shrodt	148.16	184.82	1.25
		Gibson Tower	127.12	192.22	1.51
13350 (previously reported results)	Beta AERMET, AERMOD with LOWWIND2 σ_v = 0.5 m/sec	Mt. Carmel	197.25	277.57	1.41
		East Mt.	206.89	224.65	1.09
		Shrodt	148.16	176.81	1.19
		Gibson Tower	127.12	192.22	1.51
15181	Beta AERMET, AERMOD with LOWWIND3	Mt. Carmel	197.25	276.12	1.40
		East Mt.	206.89	217.05	1.05
		Shrodt	148.16	175.42	1.18
		Gibson Tower	127.12	175.92	1.38
13350 (previously reported results)	SHARP	Mt. Carmel	197.25	225.05	1.14
		East Mt.	206.89	202.82	0.98
		Shrodt	148.16	136.41	0.92
		Gibson Tower	127.12	148.64	1.17

*Design Concentration: 99th percentile peak daily 1-hour maximum, averaged over the years modeled and monitored.

Figure 3: Gibson Ratio of Monitored to Modeled Design Concentration Values

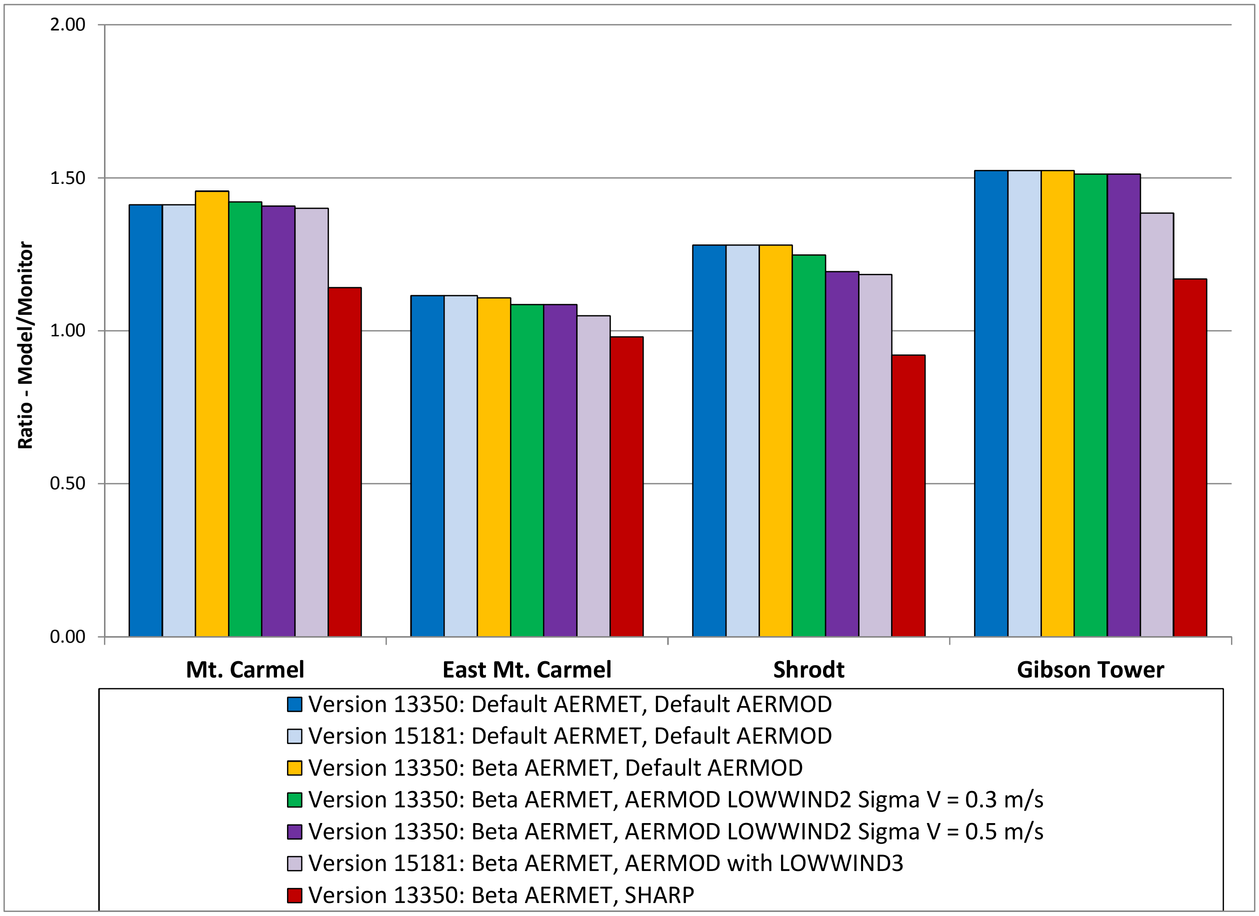
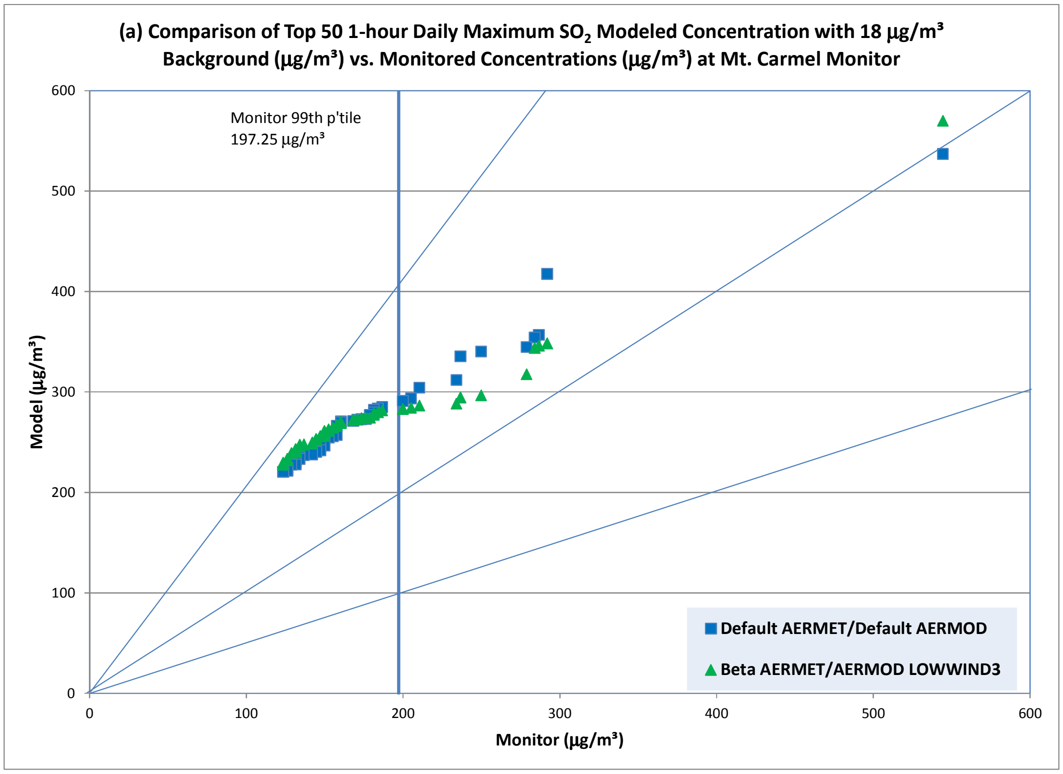
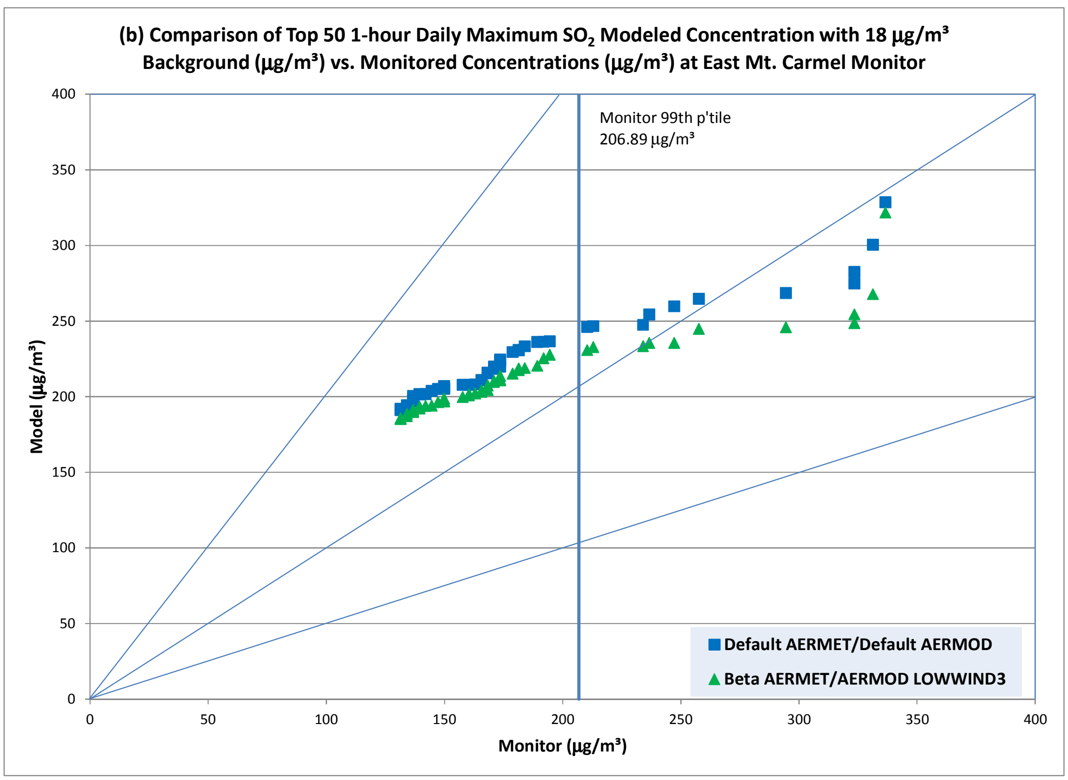
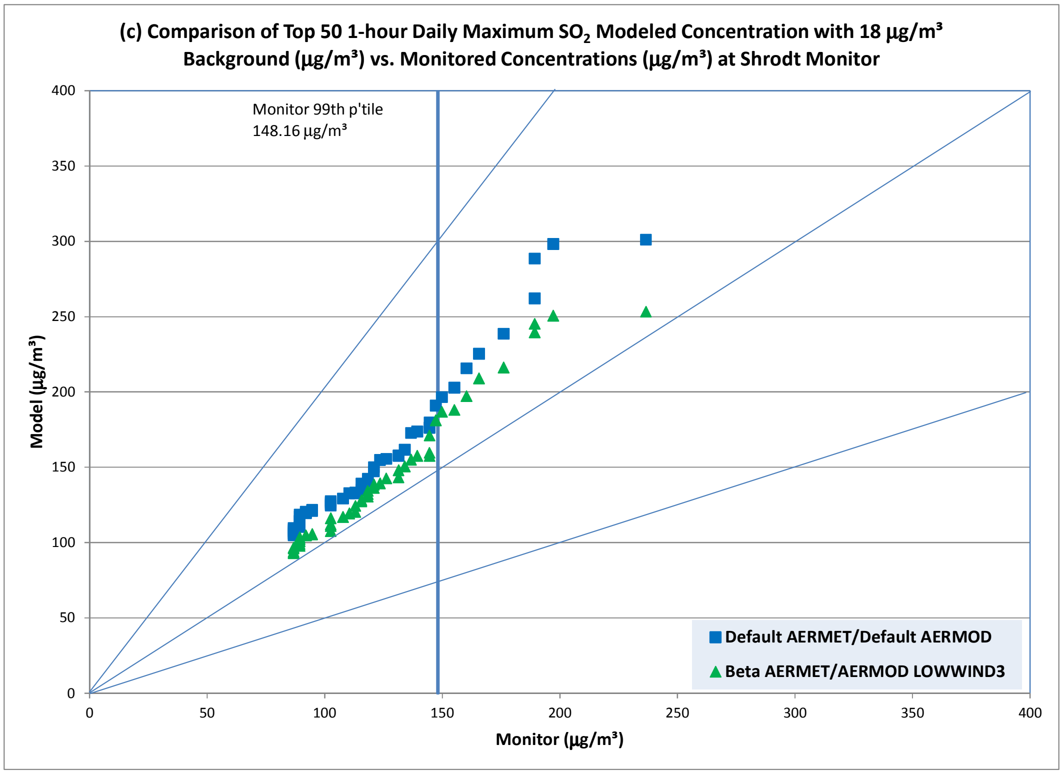
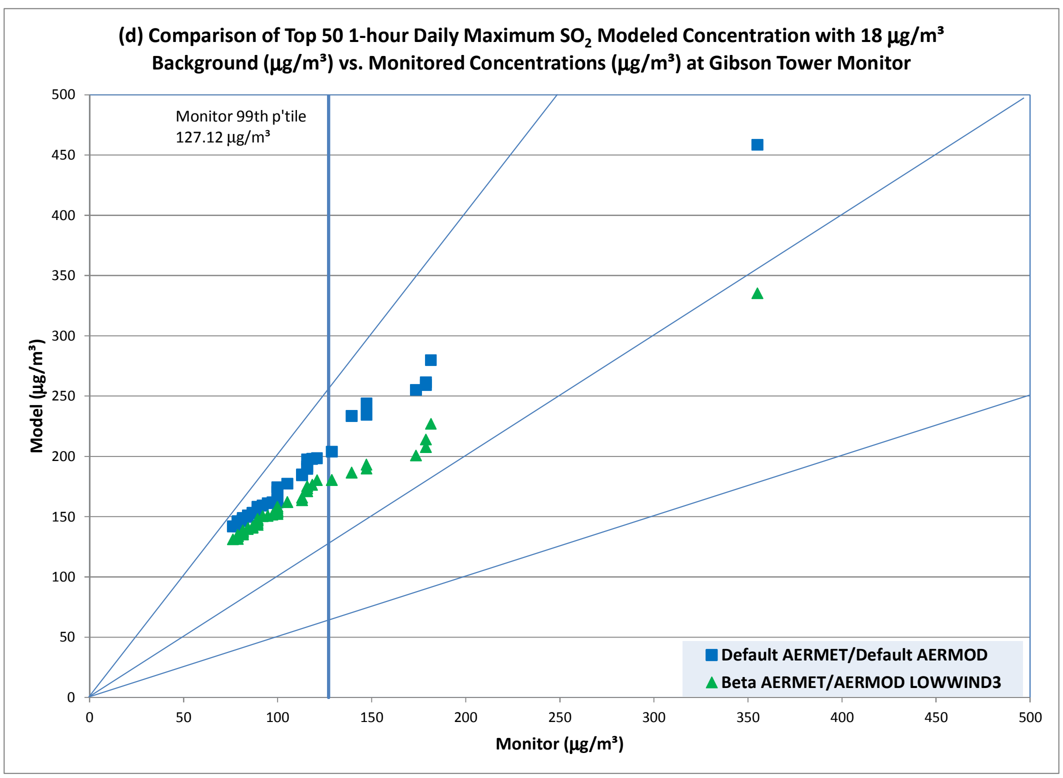


Figure 4: Gibson Q-Q Plots: Top 50 Daily Maximum 1-hour SO_2 Concentrations. (a) Mt. Carmel Monitor. (b) East Mt. Carmel Monitor. (c) Shrodt Monitor. (d) Gibson Tower Monitor






(c) Comparison of Top 50 1-hour Daily Maximum SO_2 Modeled Concentration with 18 µg/m³ Background (µg/m³) vs. Monitored Concentrations (µg/m³) at Shrodt Monitor
Monitor 99th p'tile
148.16 µg/m³
Model (µg/m³)
Monitor (µg/m³)
Default AERMET/Default AERMOD
Beta AERMET/AERMOD LOWWIND3
0
50
100
150
200
250
300
350
400

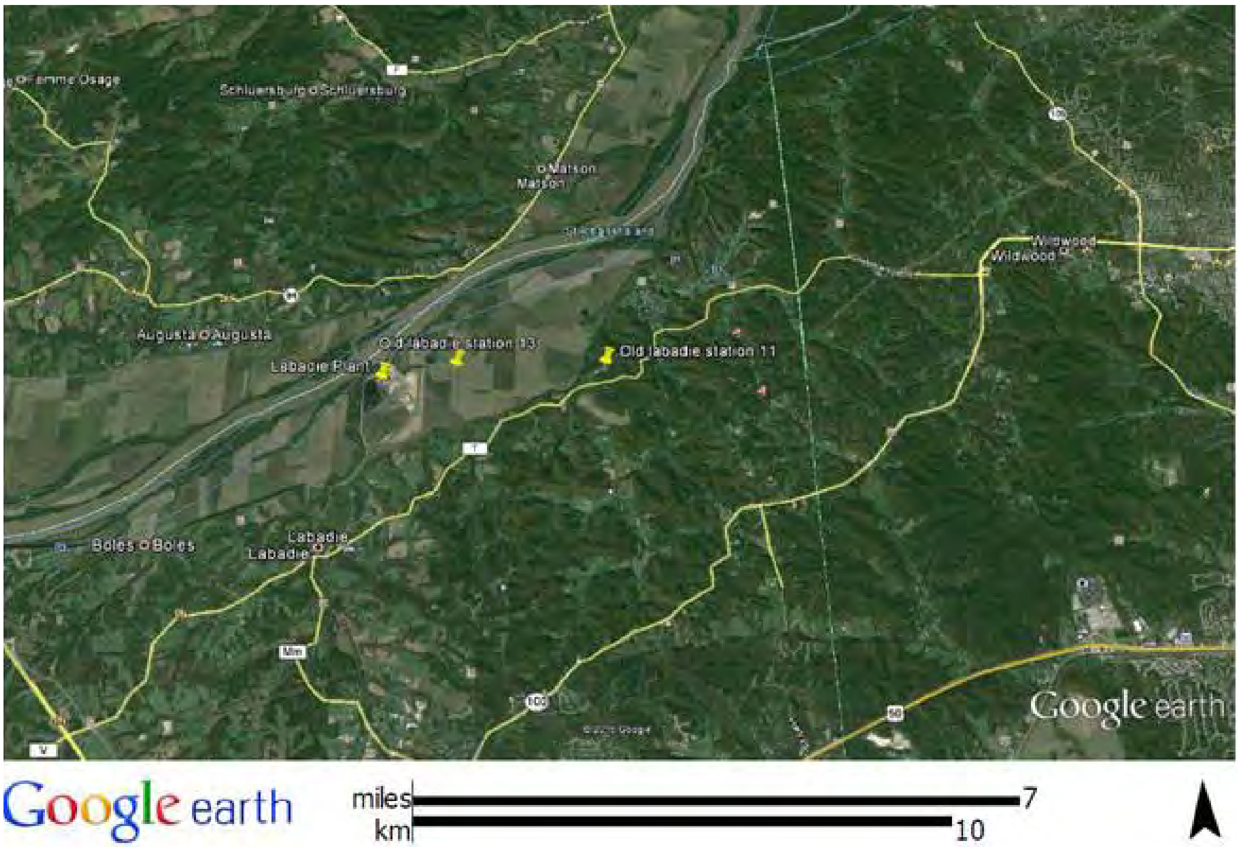

(d) Comparison of Top 50 1-hour Daily Maximum SO_2 Modeled Concentration with 18 µg/m³ Background (µg/m³) vs. Monitored Concentrations (µg/m³) at Gibson Tower Monitor
Monitor 99th p'tile
127.12 µg/m³
Model (µg/m³)
Monitor (µg/m³)
Default AERMET/Default AERMOD
Beta AERMET/AERMOD LOWWIND3
0
50
100
150
200
250
300
350
400
450
500

Appendix D

Comparison of Wind Roses from Jefferson City and Spirit of St. Louis Airports to Historical Tall-Tower Labadie Meteorological Data

Ameren has found in archived records that during the calendar year 1984, on-site meteorological data were taken at a 10-m tower (“Station 13”) as well as from the 50-m and 85-m levels on a tall-tower (“Station 17”) more reflective of stack-top conditions (213 meters) at the sites shown in Figure 1.

Figure 1: Meteorological Monitoring Sites from 1984 Data Collection Near Labadie



These stations were operated by Ameren (then Union Electric) experienced field personnel according to the applicable quality assurance guidance at that time.

Unfortunately, the hourly data gathered from this meteorological network was stored on 9-track reel tapes that no longer exist. However, hard copies of wind rose plots of the data are available for the various meteorological levels, as shown in Figure 2 for the on-site 10-m level, Figure 3 for the on-site 50-m level, and Figure 4 for the on-site 85-m level. These can be compared to the wind roses available for the KJEF and KSUS airports, available in Figures 5 and 6, respectively.

Figure 2: 1984 Wind Rose for 10-m On-site Meteorological Data Near the Labadie Energy Center

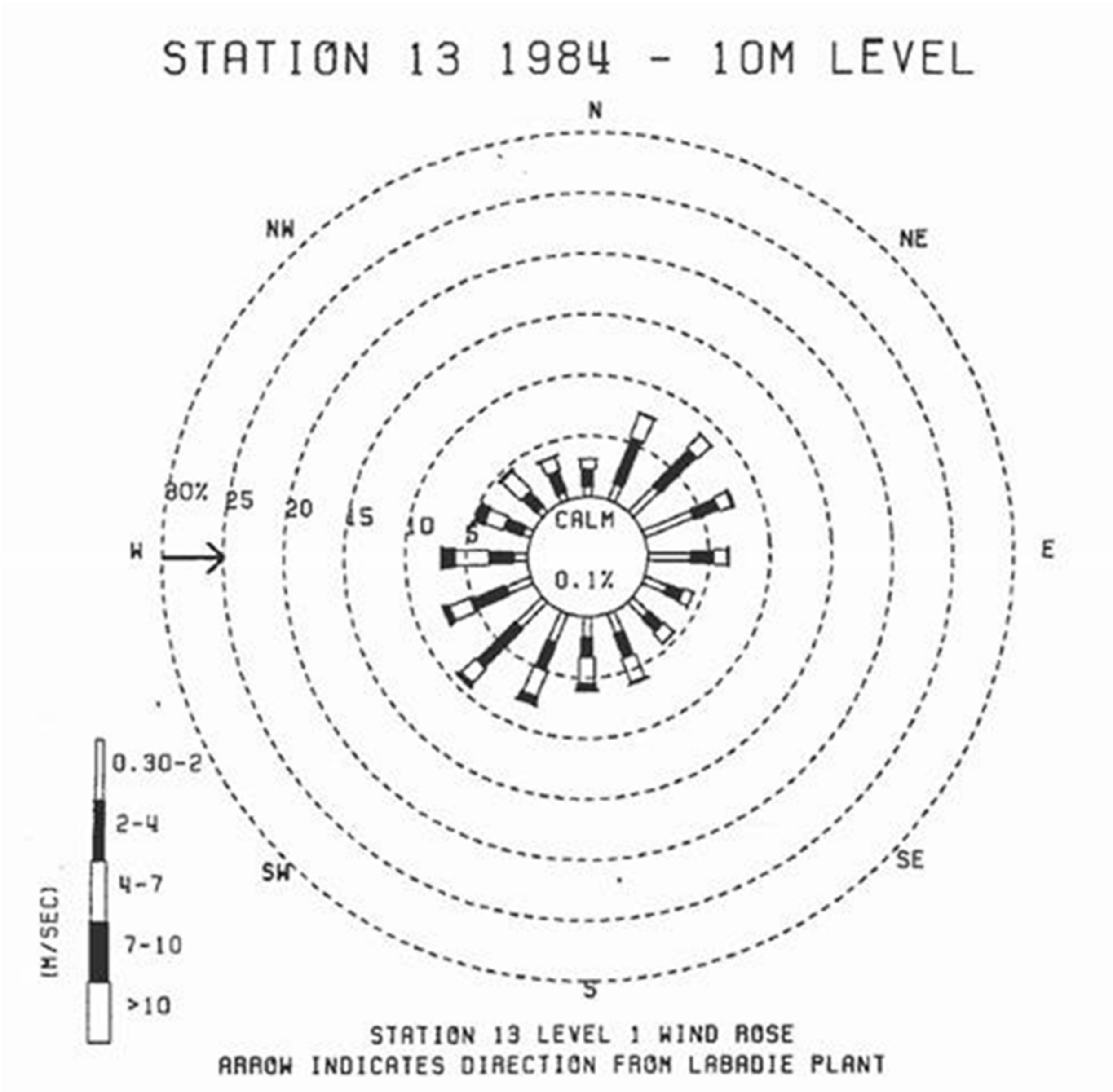


Figure 3: 1984 Wind rose for 50-m On-site Meteorological Data

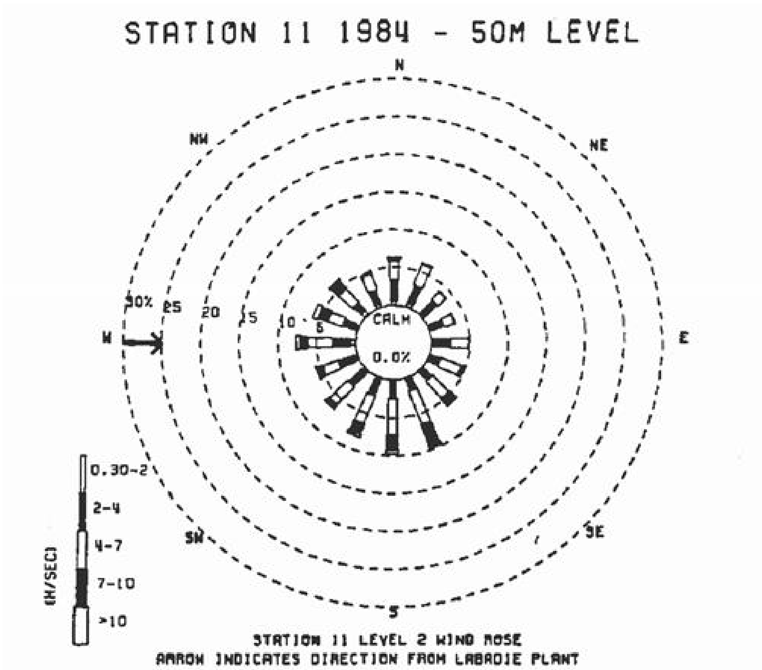


Figure 4: 1984 Wind rose for 85-m On-site Meteorological Data

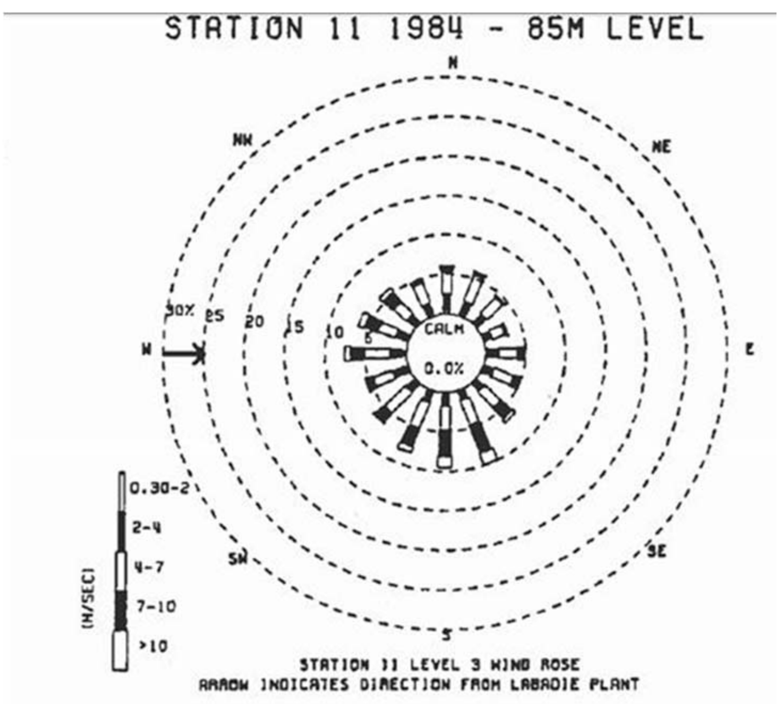


Figure 5: KJEF (Jefferson City Airport) Wind Rose (2012-2014)

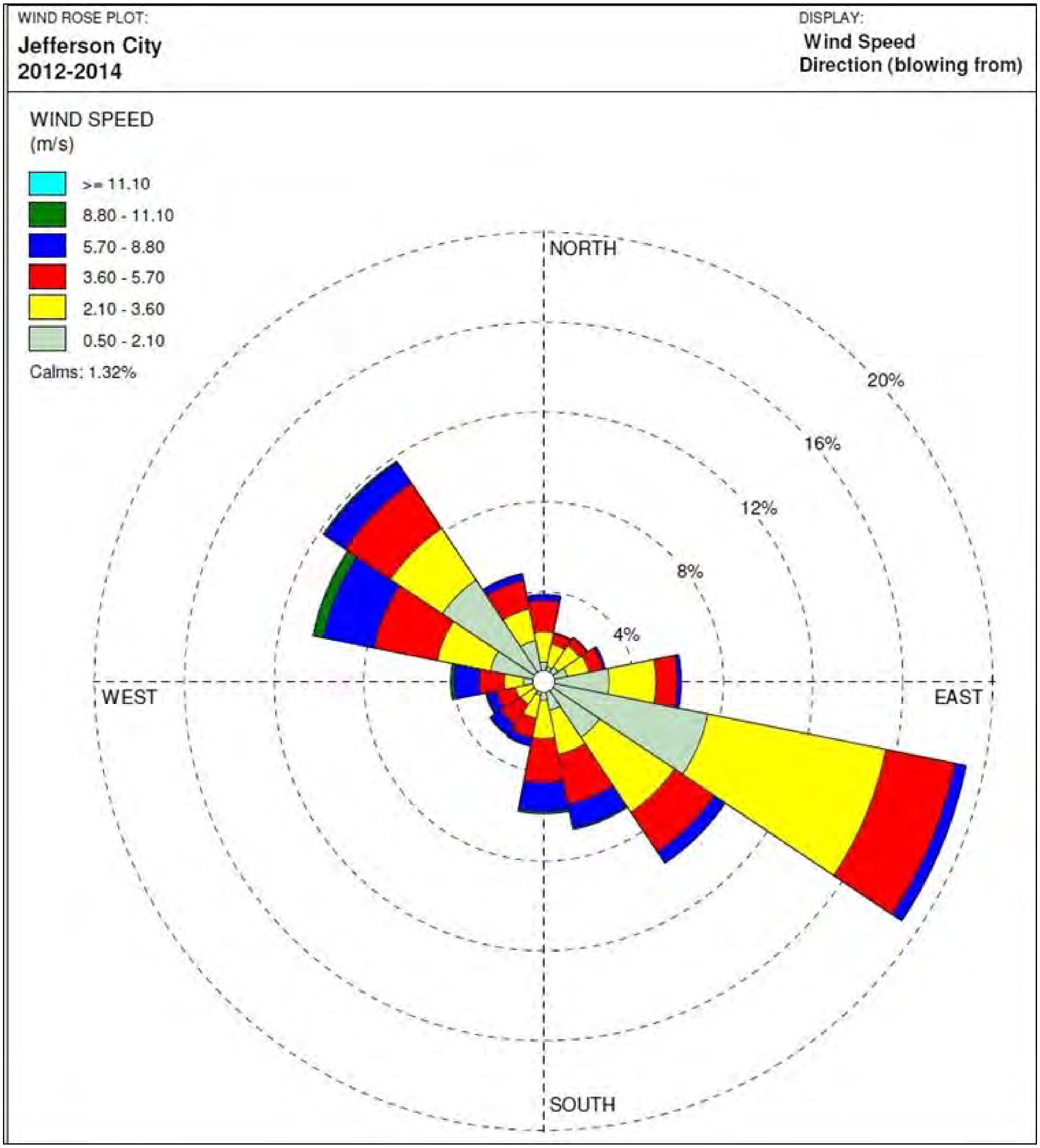
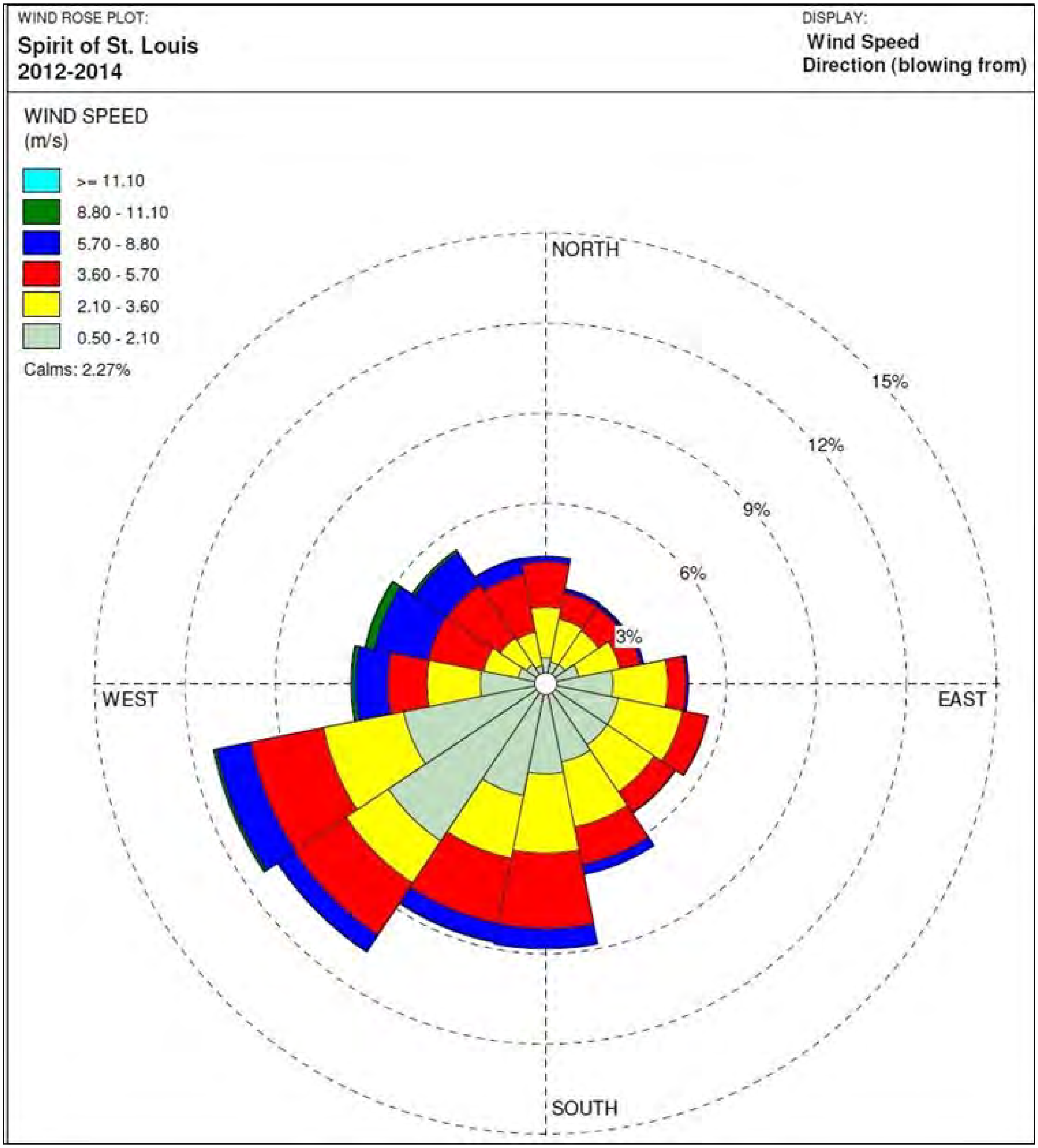


Figure 6: KSUS (Spirit of St. Louis Airport) Wind Rose (2012-2014)



It is evident from the comparison of the 10-m vs. 50-m and 85-m wind roses (Figures 2, 3, and 4, respectively), that there is a substantial difference in the wind pattern at the Labadie stack top versus the valley. While the KSUS wind pattern is more similar to the valley flow near Labadie, the KJEF wind pattern is a better match to the on-site tall tower measurements in the following respects:

- The strong alignment of the 10-m data along the Missouri River valley orientation is not at all present in the higher-level winds. Therefore, the use and reliance on the KSUS data for modeling tall stack releases from Labadie is not recommended.

- The preference for winds from the SSE and WNW from the tall tower levels is more consistent with the KJEF wind pattern. Therefore, placement of the Labadie monitors at their current locations is more in line with the upper level wind pattern seen in Figures 3 and 4.

As a result of this review of historical on-site wind data, it can be concluded that the KJEF winds are reasonably representative of upper-level flow affecting the Labadie stack-top winds.

Attachment E

Site-Specific Dispersion Model for Eastman Chemical Company's Kingsport, TN Facility

Environment

Prepared for:
Eastman Chemical Company
Kingsport, TN

Prepared by:
AECOM
Chelmsford, MA
60322358.100
July 2014

Site-Specific Dispersion Model for Eastman Chemical Company's Kingsport, TN Facility

Environment

Prepared for:
Eastman Chemical Company
Kingsport, TN

Prepared by:
AECOM
Chelmsford, MA
60322358.100
July 2014

Site-Specific Dispersion Model for Eastman Chemical Company's Kingsport, TN Facility

Prepared By Carlos Szembek

Reviewed By Robert Paine

Quality

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1.0 Introduction

1.1 Background

Eastman Chemical Company (“Eastman”) operates a large manufacturing facility (“Tennessee Operations) in Kingsport, Tennessee with coal-fired power generation. The terrain in this area features valleys and complex terrain ridges oriented WSW to ENE. A monitor in the vicinity of the Eastman manufacturing facility in Kingsport, Tennessee indicated attainment with the SO_2 National Ambient Air Quality Standards (NAAQS) until the promulgation of a much stricter 1-hour standard of 75 ppb in 2010. The area within 3 km of the facility has been included in a designated SO_2 nonattainment area[1].

In anticipation of the need to conduct a refined dispersion modeling analysis of their facility’s SO_2 emissions, Eastman initiated a comprehensive meteorological and air quality monitoring study in 2012. The 1-year on-site database that was obtained has enabled Eastman and its consultant, AECOM, to develop a refined site-specific modeling approach with evaluation using concurrent meteorological, emissions, and monitoring data at multiple sites. This document describes the site-specific application of AERMOD that is proposed for modeling emissions from Eastman’s Kingsport, TN facility.

1.2 Development of Site-Specific Dispersion Model for Kingsport, TN

The 1-year meteorological program, conducted from April 1, 2012 through March 31, 2013[2], involved a site-specific installation and operation of a 100-m tower and Doppler SODAR system to provide profiles of meteorological data as input to AERMOD for modeling the SO_2 emissions from the Eastman powerhouses. Eastman also collected SO_2 monitoring data in a network with multiple sites and archived hourly emissions data for the purpose of an analysis to verify the accuracy of the predictions of the United States Environmental Protection Agency (EPA) preferred model, AERMOD. AECOM found that AERMOD as run in default regulatory mode resulted in substantial over-predictions at the Eastman monitors.

AECOM proceeded to test AERMOD using the full year of on-site data with site-specific enhancements based upon featured derived from independent scientific research. These features include the following aspects:

- Use of low-wind speed options included in AERMET version 14134 (beta u* option),
- Use of minimum sigma-v specifications using the LOWWIND2 option in AERMOD, and
- Accounting for partial merging of buoyancy of plumes from adjacent stacks.

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[1] August 5, 2013 Federal Register notice, 78 FR 47191.

[2] The monitoring started in mid-March 2012 in a “shakedown” period, and final calibrations and shut down occurred in early June, 2013.

This report documents the 1-year database, the model evaluation procedures, the modeling options tested, and the results of the model evaluation. We conclude that the evaluation supports the use of the proposed site-specific model to assure future compliance with the 1-hour SO_2 NAAQS in Kingsport.

1.3 Organization of Report

Section 2 describes the Eastman Kingsport facility emission points in detail. It also discusses the emission controls that are being implemented to bring the area back into NAAQS attainment for SO_2. Section 3 describes the meteorological and monitoring field program between April 1, 2012 and March 31, 2013. Section 4 discusses how the meteorological data was processed for input to AERMOD. The evaluation procedures used to test dispersion model performance for AERMOD in default mode are presented in Section 5. A discussion of regional background concentrations is presented in Section 6. The performance evaluation of AERMOD in default mode for the full year of on-site data is presented in Section 7. Its poor performance provided insights for areas of improvement that led to the enhancements in the proposed site-specific model, whose formulation is described in Section 8. Section 9 presents the evaluation results of the site-specific modeling for comparison to the evaluation of the default model. Section 10 presents conclusions that the proposed site-specific model satisfies the conditions noted in Appendix W for adoption of an alternative model as proposed, and that this model should be approved by the Tennessee Department of Environmental Conservation (TDEC) and EPA for future applications with emissions from the Eastman Chemical Company facility in Kingsport, TN.

2.0 Eastman Chemical Company's Kingsport, TN Facility

2.1 Eastman Plant Setting

Eastman operates coal-fired boilers that constitute major SO_2 sources. The SO_2 emissions come from three main boiler groups that are shown in Figure 2-1: two B-83 stacks are about 70 m high, five B-253 stacks are about 76 m high, and the B-325 stack is about 114 m high.

Kingsport is located in the northeast corner of Tennessee, and shares an airport ("Tri-Cities") with regional cities of Johnson City and Bristol. This portion of Tennessee includes parts of three major geological formations: the Blue Ridge Mountains on the border with North Carolina in the east, the main Appalachian Mountains with the ridge and valley system (where Kingsport is located), and the Cumberland Plateau toward central Tennessee. The topography of the area is shown in Figure 2-2, which indicates that Kingsport is in a valley between ridges. The wind rose from the Tri-Cities airport, shown in Figure 2-3, reflects the general WSW-ENE alignment of the terrain features and the channeling of the winds accordingly. Figure 2-2 indicates that a prominent terrain feature to the west of Kingsport is Bays Mountain.

2.2 History of SO_2 Monitoring in Kingsport, TN

Before the 2012-2013 field study, historical SO_2 monitoring data had been taken from up to four stations, as shown in Figure 2-4. From that information, it was determined that the peak short-term monitored concentrations at the Ross N Robinson monitor were as high or higher than those at the other monitors, so that monitor was maintained to the present day while the others were eventually shut down. Until the 1-hour SO_2 NAAQS went into effect, the monitored concentrations indicated compliance with the pre-existing standards. However, due to the stringency of the new standard, the monitoring data now indicates concentrations that are above the 1-hour SO_2 NAAQS. The 2009-2011 99^{th} percentile peak daily 1-hour maximum concentration, averaged over the 3 years (the "design concentration") is 196 ppb[3], which is about 2.6 times the NAAQS of 75 ppb.

2.3 SO_2 Emissions from Eastman Boiler Complexes

Each of the five stacks at the 253 Powerhouse serves identical boilers (Boilers 25 – 29, refer to Figure 2-1) which provide steam and electricity to the Tennessee Operations facility. These boilers, installed during the 1960s and 1970s, were designed as coal-fired boilers and are equipped with electrostatic precipitators for particulate matter control. Eastman is implementing a project to convert each of these to natural gas combustion, in conjunction with the State of Tennessee's State Implementation Plan for the Best Available Retrofit Technology (BART) implementation as part of the Regional Haze Rule

[3] As reported in EPA's Technical Support Document for the Tennessee nonattainment designations, available at http://www.epa.gov/air/sulfurdioxide/designations/tsd/04_TN_tsd.pdf

The stack at the 325 Powerhouse serves two coal-fired boilers, Boiler 30 and Boiler 31 and is modeled as a single emission source. Boiler 30 is equipped with a spray dryer absorber and electrostatic precipitator to control particulate matter and acid gases. Boiler 31 is equipped with a spray dryer absorber and fabric filter to control particulate matter and acid gases.

Stack B at the 83 Powerhouse serves five coal-fired boilers (Boilers 18 – 22) and Stack C serves two coal-fired boilers (Boilers 23 and 24). Hence two emission sources are modeled for the 83 Powerhouse. All of the 83 boilers are equipped with electrostatic precipitators for particulate matter control.

These fourteen boilers, along with three other backup natural gas fired boilers with minimal SO_2 emissions (B-423), provide process steam and most of the electrical power needed to operate Tennessee Operations. The combination of boilers and boiler operating loads at any given time depends on manufacturing demands along with availability of boilers as each boiler has annual scheduled shutdowns. Table 2-1 lists the locations (UTM, NAD27), annually averaged emission rates and stack parameters for the eight modeled emission sources.

Figure 2-1: Power Houses at the Eastman Kingsport, TN Complex

Figure 2-2 Topographic Map of the Kingsport, TN Area

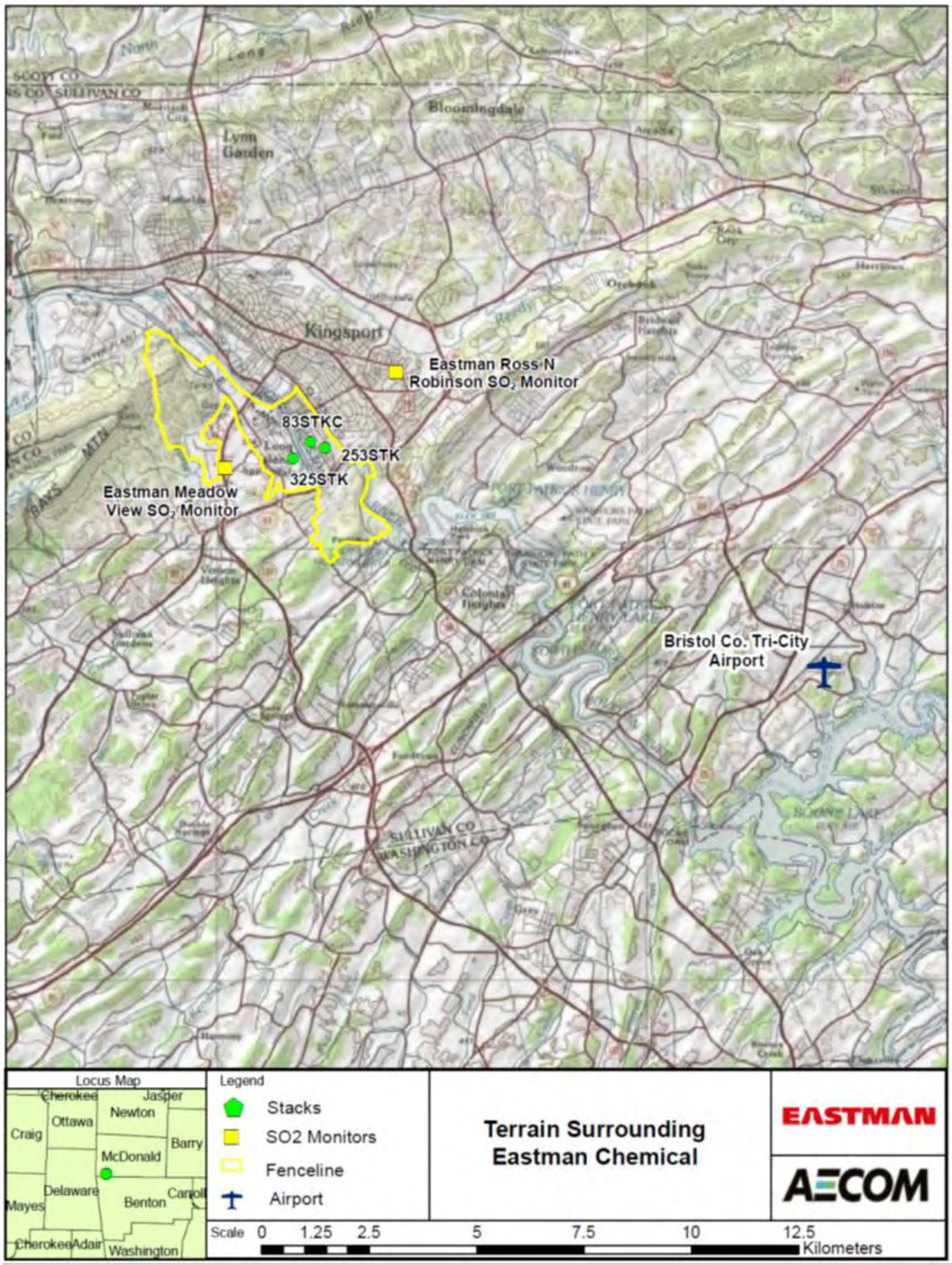

Figure 2-3 5-Year Wind Rose from Tri-Cities Airport

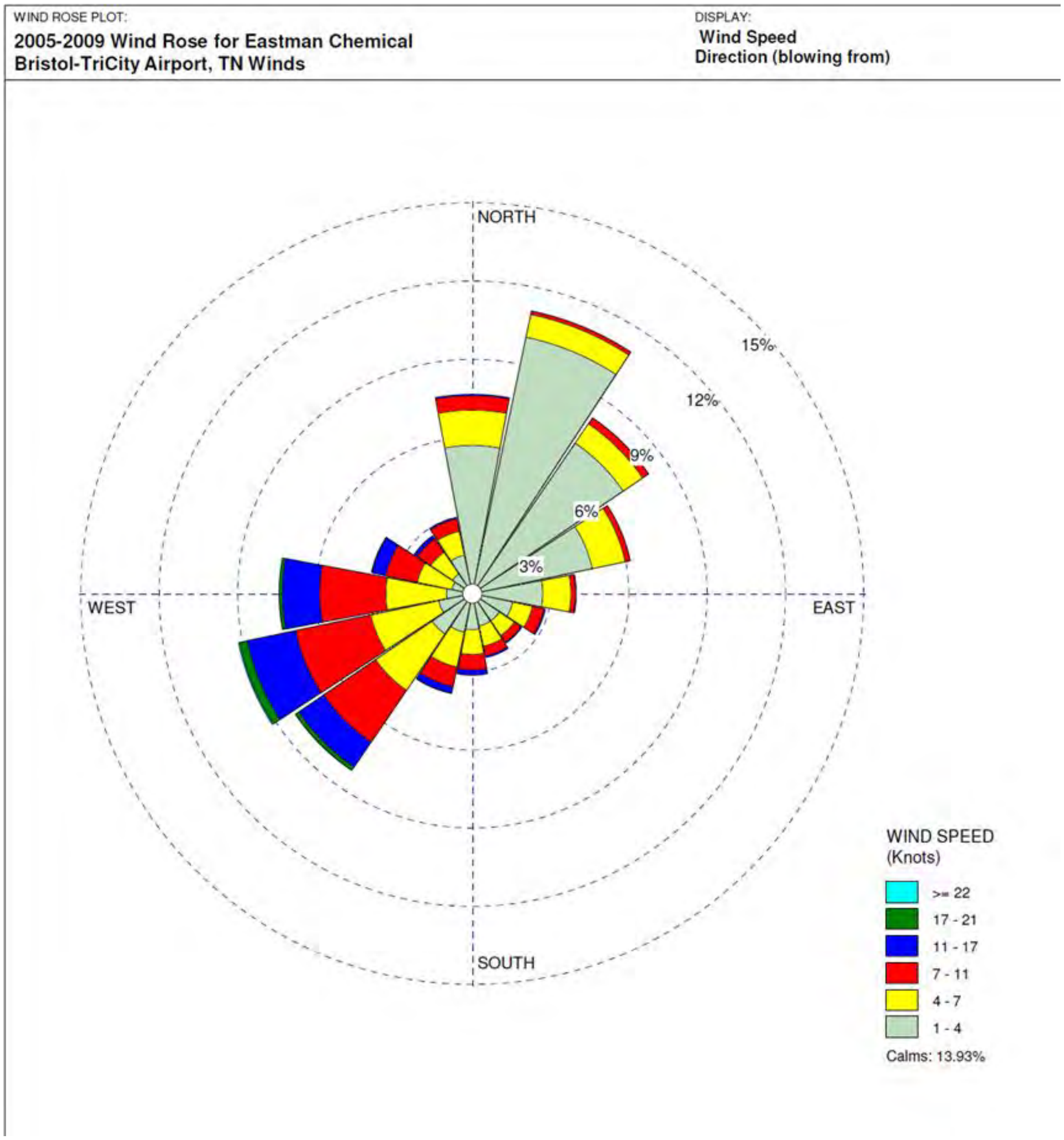

Figure 2-4 Locations of Historical SO_2 Monitors Relative to the Eastman Plant

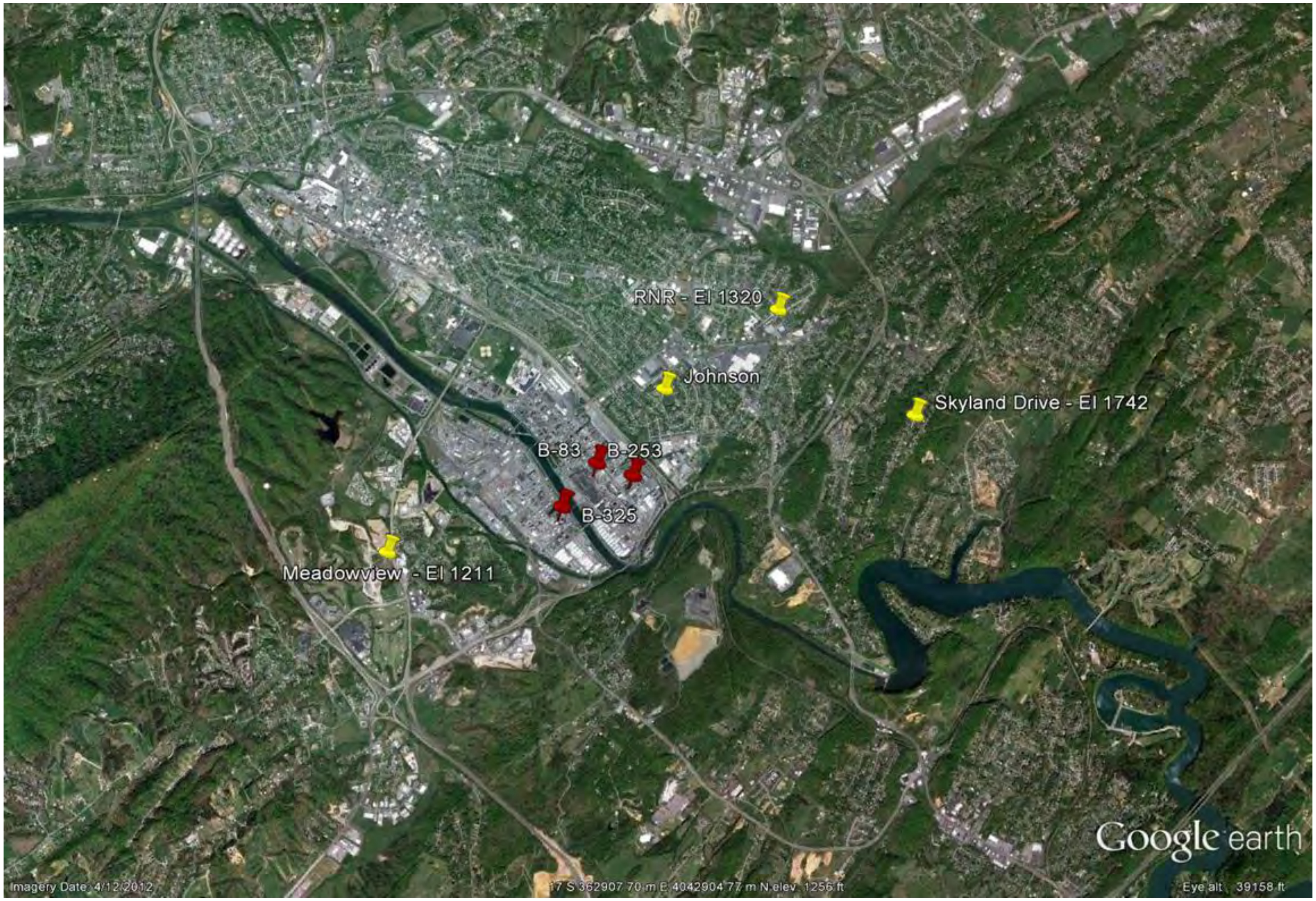

Table 2-1: Eastman Chemical SO_2 Source Locations, Emissions and Stack Parameters

Powerhouse	Stack(s)	UTM-X (m)	UTM-Y (m)	Base Elev. (m)	Stack Ht. (m)	Stack Diam. (m)	Annually Averaged Emission Rate (g/s)	Annually Averaged Stack Temp. (K)	Annually Averaged Exit Velocity (m/s)
83	18-22	362205.8	4042493.6	368.8	70.1	4.27	61.2	451.8	9.00
	23-24	362173.1	4042542.2	368.8	70.1	4.27	93.2	434.0	9.28
253	25	362515.1	4042333.2	373.7	76.2	2.44	83.4	397.6	17.52
	26	362530.1	4042342.0	373.7	76.2	2.44	86.1	392.6	18.41
	27	362544.7	4042351.8	373.7	76.2	2.44	86.4	406.6	17.72
	28	362557.8	4042361.0	373.7	76.2	2.44	84.7	404.7	17.43
	29	362571.5	4042370.6	373.7	76.2	2.44	85.8	408.6	18.25
325	30-31	361800.0	4042105.0	367.7	114.3	3.05	37.2	354.5	26.38

2.4 Regional SO_2 Emission Sources

EPA's final Technical Support Document[3] for the Tennessee nonattainment designations indicated that there are only two other SO_2 emission sources in the vicinity of the Eastman facility, as shown in Figure 2-5, and these two are less than 100 tons per year. Therefore, the regional SO_2 background in the vicinity of Kingsport is very low and there are no local sources identified by EPA that remain to be explicitly modeled.

2.5 Planned SO_2 Reductions at Eastman

Eastman is in the process of making reductions in SO_2 emissions at the Kingsport plant in accordance with BART requirements as well as the SO_2 nonattainment designation. The reductions involve a fuel switch from coal firing to natural gas firing at the B-253 boiler complex. This reduction is expected to reduce total plant SO_2 emissions to about 1/3 of the current levels. Due to the lack of regional SO_2 sources (and, thus a low background concentration, as noted by the monitoring), this reduction would be expected to result in a future monitored concentration that is below the NAAQS because the currently monitored design concentration is less than 3 times the NAAQS. However, the NAAQS is still quite stringent, such that a dispersion model that has an over-prediction bias could provide a false indication of a NAAQS violation. Therefore, Eastman has engaged in a comprehensive meteorological and air quality monitoring program to provide information for the purpose of using a dispersion model with an over-prediction bias that is lower than that of the default AERMOD model to demonstrate future NAAQS compliance in Kingsport. The field study used to support the site-specific dispersion model is described in the next section.

Figure 2-5 EPA's Final Technical Support Document Depiction of Area SO_2 Sources Near Kingsport

3.0 Full-Year Field Study to Support Site-Specific Model

3.1 Meteorological Monitoring Network Design

Eastman engaged AECOM to provide consulting advice to address the need for a site-specific database to support a dispersion model with relatively unbiased model predictions. AECOM determined from a review of the sources and topography in the area that EPA's guideline model, AERMOD[4], would likely be the first choice for the model to consider. Due to the complex terrain in the area, AECOM recommended that Eastman should acquire multiple-level meteorological data for input to AERMOD, based upon previous sensitivity studies[5] in terrain settings and EPA's use of site-specific data in its evaluation[6] of AERMOD. This general approach was first presented to TDEC and EPA Region IV in a meeting held in Atlanta on October 31, 2011.

The resulting plan for meteorological measurements led to the installation of a 100-meter meteorological tower equipped with multiple levels of meteorological sensors (at 2, 10, 50, and 100 m) and a SOund Detection And Ranging (SODAR) wind profiler system (with measurements starting at 50 m and extending upward in 50-m increments to 500 m). The data collected by these instruments was used as input to AERMOD, which was developed to accommodate multiple levels of meteorological data to more accurately predict vertical profiles of meteorological variables used in the modeling. For the monitoring program, the EPA Guidelines for Air Quality Modeling (40 CFR Part 51, Appendix W[7]) and EPA's meteorological monitoring guidance[8] provided the general guidance for sensor and parameter selection and siting of the tower and SODAR. For the SO_2 monitoring conducted in conjunction with this program, EPA's Quality Assurance Handbook for Air Pollution Measurement Systems[9] was followed.

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4 Documentation for AERMOD is available at http://www.epa.gov/ttn/scram/dispersion_prefrec.htm#aermod.

5 See, for example a study presented at the 2001 Air & Waste Management Specialty Conference: Paine, R.J., 2001. Meteorological Input Data for AERMOD Applications. Air & Waste Management Association Specialty Conference on Guideline on Air Quality Models: A New Beginning. Newport, Rhode Island. April, 2001

6 This study is available at http://www.epa.gov/ttn/scram/7thconf/aermod/aermod_mep.pdf, and the supporting databases are available at http://www.epa.gov/ttn/scram/dispersion_prefrec.htm#aermod.

7 Available at http://www.epa.gov/ttn/scram/guidance_permit.htm#appw.

8 U.S. EPA. Meteorological Monitoring Guidance for Regulatory Modeling Applications. Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina. EPA 454/R 99 005. February 2000. Available at http://www.epa.gov/scram001/guidance/met/mmgrma.pdf.

9 The monitoring was conducted in accordance with the EPA guidance at the time, available at http://www.epa.gov/ttnamti1/archive/files/ambient/criteria/reldocs/4-87-007.pdf. This guidance was updated after the monitoring program ended; the 2013 guidance is available at http://www.epa.gov/ttnamti1/files/ambient/pm25/qa/QA-Handbook-Vol-II.pdf.

Eastman submitted a quality assurance plan for the meteorological monitoring to TDEC and EPA on January 5, 2012. Comments were received from both TDEC and EPA, and a revised (final) plan was submitted to the agencies on February 22, 2012 along with responses to comments received. No further agency comments were received, and the meteorological monitoring network went into operation officially on April 1, 2012 after a few days of "shakedown" operation.

Table 3-1 provides a list of the meteorological parameters included in the field study. As indicated in the monitoring plan reviewed by TDEC and EPA, input to AERMET consisted of parameters measured on the 100-m tower up to the 100-m level, and at incremental 50-m levels from 150 m to 500 m from the SODAR. SODAR data from the 50-m and 100-m levels were available for comparison to the tower data for quality assurance purposes. An independent audit of the meteorological measurements was conducted by Air Resources Specialists, Inc. in May, 2012. Their audit report, issued May 25, 2012, indicated that all meteorological instruments were within EPA-recommended accuracy goals, and that there were no adverse findings from the audit. Representatives of TDEC and EPA visited the monitoring network on December 11, 2012 and were escorted to the meteorological monitoring site as well as the SO_2 monitoring sites discussed in the next sub-section. Further updates regarding the site-specific measurement program were presented to TDEC and EPA on March 18, 2013. TDEC and EPA were advised in the December 2012 and March 2013 meetings that Eastman was testing site-specific modeling options and that the default AERMOD model showed significant over-predictions.

3.2 SO_2 Monitoring

During the April 1, 2012 – March 31, 2013 period of the meteorological measurement program, Eastman operated three SO_2 monitors for this full period (Ross N Robinson, Meadowview, and Skyland Drive – these were historical sites). Two other monitors were operated for a portion of this period (B-267 Parking Lot and Bays Mountain – these were new sites). Figure 3-1 provides a map showing the locations of the meteorological monitoring site as well as the SO_2 monitoring sites.

3.3 Meteorological Tower Data Capture Summary

The meteorological tower parameters generally had data captures above 90% for each month of the monitoring program. One exception is that for the months of July and August, 2012, data capture for precipitation was less than 90% due to a mechanical failure of the rain gauge. In December, 2012, foreign debris, i.e., vegetation, in the rain gauge also resulted in data capture below 90%. Each of the other months had data captures above 90% for precipitation, which was principally used to provide quality assurance for the SODAR data review.

The data capture for the April 2012-March 2013 measurement period for the meteorological tower parameters was above 90% (and often at 100%) for each parameter. Table 3-1 shows the data capture for all the parameters measured on the meteorological tower.

3.4 SODAR Data Capture Summary

AERMOD accepts data from multiple levels, and the measurement program was designed to accommodate the tower data with supplemental data from the SODAR. Data capture for the SODAR data was generally 90% or greater up to around 400 meters except for portions of the first quarter of 2013, as described further below. Table 3-2 shows the data capture for all the parameters measured by the SODAR.

Figure 3-1: Locations of Meteorological Tower and SO2 Monitors

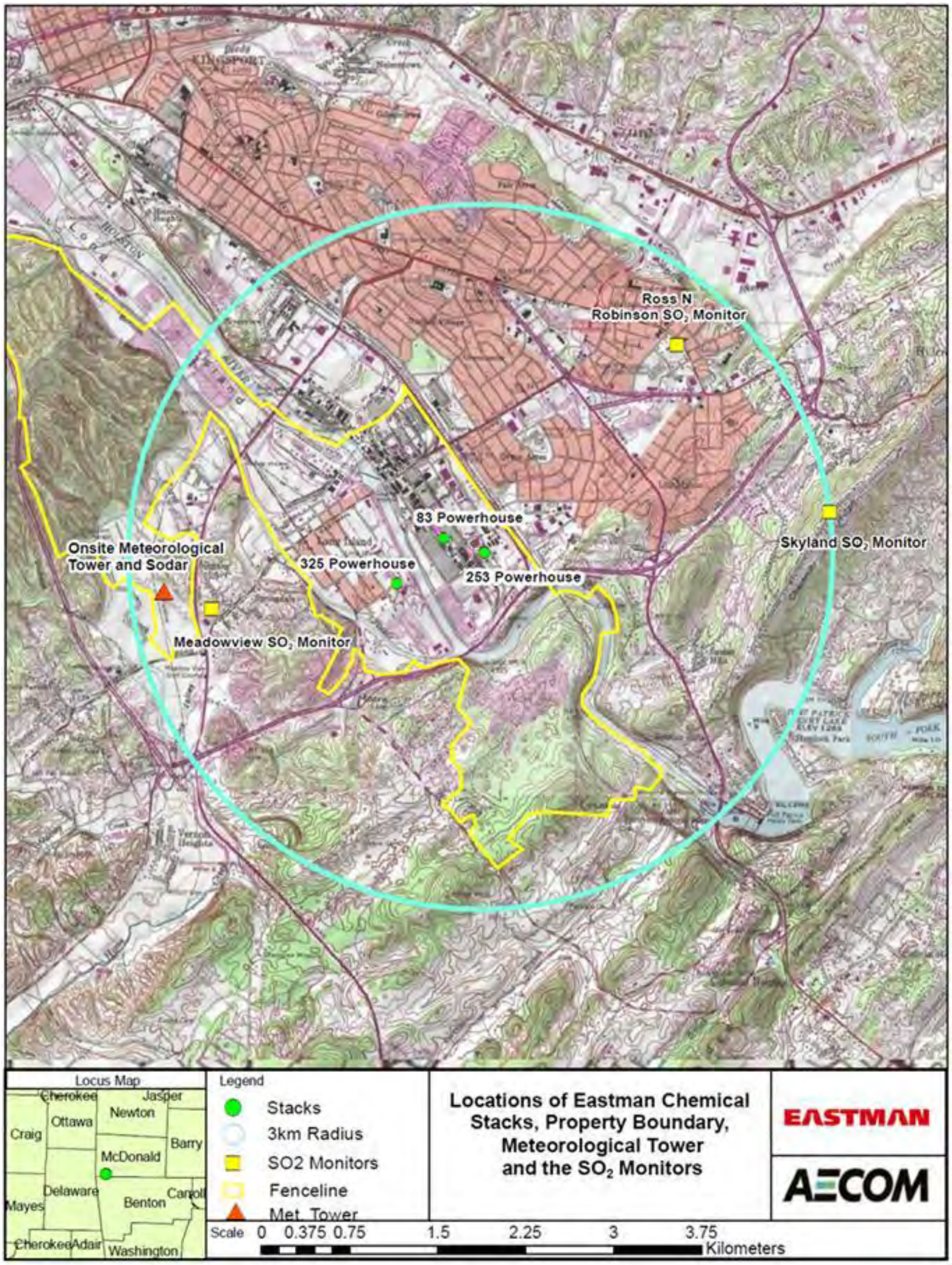

Table 3-1: Data Capture for the Meteorological Tower; April, 2012 - March, 2013

Met Tower Level	Parameter	1-Apr	May	Jun	2nd Qtr	Jul	Aug	Sep	3rd Qtr	Oct	Nov	Dec	4th Qtr	Jan	Feb	Mar	1st Qtr	Cum Avg.
2 Meter	2M-Temp	100	100	100	**100**	100	100	100	**100**	100	100	100	**100**	100	100	100	**100**	**100**
	2M- Tot Solar	100	94	100	**98**	100	100	100	**100**	100	100	100	**100**	100	100	100	**100**	**100**
	2M- RH	100	100	100	**100**	100	100	100	**100**	100	100	100	**100**	100	100	100	**100**	**100**
	2M- Bar Press	100	100	100	**100**	100	100	98	**99**	99	100	100	**100**	100	100	100	**100**	**100**
	2M- Precip	100	100	100	**100**	68	79	100	**82**	92	98	87	**92**	100	100	100	**100**	**94**
10 Meter	10M- HWS	99	100	100	**100**	100	100	99	**100**	100	100	100	**100**	100	100	100	**100**	**100**
	10M- HWD	99	100	100	**100**	100	100	99	**100**	100	100	100	**100**	100	100	100	**100**	**100**
	10M- HWD SD1	99	100	100	**100**	100	100	99	**100**	100	100	100	**100**	100	100	100	**100**	**100**
	10M- HWS SU	99	100	100	**100**	100	100	99	**100**	100	100	100	**100**	100	100	100	**100**	**100**
	10M- VWS	99	100	100	**100**	100	100	99	**100**	100	100	100	**100**	100	100	100	**100**	**100**
	10M- VWS Std	99	100	100	**100**	100	100	99	**100**	100	100	100	**100**	100	100	100	**100**	**100**
	10M- Temp	100	100	100	**100**	100	100	99	**100**	100	100	100	**100**	100	100	100	**100**	**100**
	Delta T 2-10M	100	100	100	**100**	100	100	99	**100**	100	100	100	**100**	100	100	100	**100**	**100**
50 Meter	50M- HWS	99	100	100	**100**	100	100	99	**100**	100	100	100	**100**	100	100	100	**100**	**100**
	50M- HWD	99	100	100	**100**	100	100	99	**100**	100	100	100	**100**	100	100	100	**100**	**100**
	50M- HWD SD1	99	100	100	**100**	100	100	99	**100**	100	100	100	**100**	100	100	100	**100**	**100**
	50M- HWS SU	99	100	100	**100**	100	100	99	**100**	100	100	100	**100**	100	100	100	**100**	**100**
	50M- VWS	99	100	100	**100**	100	100	99	**100**	100	100	100	**100**	100	100	100	**100**	**100**
	50M- VWS Std	99	100	100	**100**	100	100	99	**100**	100	100	100	**100**	100	100	100	**100**	**100**
	50M- Temp	99	100	100	**100**	100	100	99	**100**	100	100	100	**100**	100	100	100	**100**	**100**
	Delta T 10-50M	100	100	100	**100**	100	100	99	**100**	100	100	100	**100**	100	100	100	**100**	**100**

Met Tower Level	Parameter	1-Apr	May	Jun	2nd Qtr	Jul	Aug	Sep	3rd Qtr	Oct	Nov	Dec	4th Qtr	Jan	Feb	Mar	1st Qtr	Cum Avg.
100 Meter	100M-HWS	99	100	100	**100**	100	100	99	**100**	100	100	100	**100**	100	100	100	**100**	**100**
	100M-HWD	99	100	100	**100**	100	100	99	**100**	100	100	100	**100**	100	100	100	**100**	**100**
	100M-HWD SD1	99	100	100	**100**	100	100	99	**100**	100	100	100	**100**	100	100	100	**100**	**100**
	100M-HWS SU	99	100	100	**100**	100	100	99	**100**	100	100	100	**100**	100	100	100	**100**	**100**
	100M-VWS	99	100	100	**100**	100	100	99	**100**	100	100	100	**100**	95	93	100	**96**	**99**
	100M-VWS Std	99	100	100	**100**	100	100	99	**100**	100	100	100	**100**	95	93	100	**96**	**99**
	100M-Temp	99	100	100	**100**	100	100	99	**100**	100	100	100	**100**	100	100	100	**100**	**100**
	Delta T 10-100M	100	100	100	**100**	100	100	99	**100**	100	100	100	**100**	100	100	100	**100**	**100**

Table 3-2: Data Coverage for SODAR; April, 2012 - March, 2013

SODAR Level	Parameter	1-Apr	May	Jun	2nd Qtr	Jul	Aug	Sep	3rd Qtr	Oct	Nov	Dec	4th Qtr	Jan	Feb	Mar	1st Qtr	Cum Avg.
50 Meter	50M- WSP	87	99	100	**95**	98	99	97	**98**	91	91	98	**93**	85	40	89	**71**	**90**
	50M-WDR	87	99	100	**95**	99	99	97	**98**	91	91	98	**93**	85	41	89	**72**	**90**
	50M- SD1	84	98	99	**94**	98	98	95	**97**	88	88	94	**90**	81	37	85	**68**	**87**
	50M- VWS	86	99	100	**95**	99	99	97	**98**	91	92	98	**94**	85	42	89	**72**	**90**
	50M- SIG W	84	98	99	**94**	98	98	96	**97**	88	89	94	**90**	81	38	86	**68**	**87**
100 Meter	100M-WSP	87	98	100	**95**	97	99	98	**98**	91	91	98	**93**	85	40	89	**71**	**89**
	100M-WDR	88	98	100	**95**	97	99	98	**98**	91	93	98	**94**	85	42	89	**72**	**90**
	100M-SD1	83	97	99	**93**	97	98	97	**97**	90	89	95	**91**	83	38	86	**69**	**88**
	100M-VWS	84	98	100	**94**	97	99	98	**98**	91	93	98	**94**	86	42	90	**73**	**90**
	100M- SIG W	83	97	99	**93**	97	98	97	**97**	90	91	95	**92**	83	39	87	**70**	**88**
150 Meter	150M-WSP	86	99	100	**95**	98	99	98	**98**	91	91	98	**93**	85	37	88	**70**	**89**

SODAR Level	Parameter	1-Apr	May	Jun	2nd Qtr	Jul	Aug	Sep	3rd Qtr	Oct	Nov	Dec	4th Qtr	Jan	Feb	Mar	1st Qtr	Cum Avg.
	150M-WDR	86	99	100	**95**	98	99	98	**98**	90	91	98	**93**	85	38	88	**70**	**89**
	150M-SD1	71	98	100	**90**	98	98	96	**97**	90	89	94	**91**	83	27	83	**64**	**86**
	150M-VWS	73	99	100	**91**	98	99	98	**98**	91	92	97	**93**	85	35	87	**69**	**88**
	150M- SIG W	71	98	100	**90**	98	99	97	**98**	90	90	94	**91**	83	29	84	**65**	**86**
200 Meter	200M-WSP	83	99	99	**94**	98	98	97	**98**	90	90	96	**92**	85	30	85	**67**	**88**
	200M-WDR	83	99	99	**94**	98	98	97	**98**	90	90	96	**92**	85	31	85	**67**	**88**
	200M-SD1	65	98	99	**87**	97	98	96	**97**	90	88	93	**90**	83	21	81	**62**	**84**
	200M-VWS	67	99	99	**88**	98	98	98	**98**	90	91	96	**92**	84	27	83	**65**	**86**
	200M- SIG W	65	98	99	**87**	97	98	97	**97**	90	90	93	**91**	83	22	81	**62**	**84**
250 Meter	250M-WSP	80	98	99	**92**	97	98	97	**97**	90	85	95	**90**	84	24	84	**64**	**86**
	250M-WDR	80	98	99	**92**	97	98	97	**97**	90	85	95	**90**	84	26	84	**65**	**86**
	250M-SD1	60	98	99	**86**	97	98	96	**97**	89	84	91	**88**	82	17	78	**59**	**82**
	250M-VWS	62	98	99	**86**	97	98	97	**97**	90	85	94	**90**	84	23	82	**63**	**84**
	250M- SIG W	60	98	99	**86**	97	98	96	**97**	90	84	91	**88**	82	18	78	**59**	**83**
300 Meter	300M-WSP	79	98	99	**92**	96	98	96	**97**	89	84	95	**89**	84	19	77	**60**	**85**
	300M-WDR	79	98	99	**92**	96	98	97	**97**	90	84	95	**90**	84	21	77	**61**	**85**
	300M-SD1	58	97	99	**85**	95	98	95	**96**	88	82	90	**87**	81	12	67	**53**	**80**
	300M-VWS	59	98	99	**85**	96	98	97	**97**	89	83	92	**88**	83	17	70	**57**	**82**
	300M- SIG W	58	97	99	**85**	95	98	96	**96**	89	82	90	**87**	81	13	67	**54**	**80**
350 Meter	350M-WSP	75	97	98	**90**	95	98	96	**96**	89	82	93	**88**	83	18	72	**58**	**83**

SODAR Level	Parameter	1-Apr	May	Jun	2nd Qtr	Jul	Aug	Sep	3rd Qtr	Oct	Nov	Dec	4th Qtr	Jan	Feb	Mar	1st Qtr	Cum Avg.
	350M-WDR	75	97	98	**90**	95	98	96	**96**	90	82	93	**88**	83	18	72	**58**	**83**
	350M-SD1	55	97	98	**83**	95	97	95	**96**	87	80	89	**85**	79	9	59	**49**	**78**
	350M-VWS	56	97	98	**84**	95	98	96	**96**	88	81	91	**87**	82	14	62	**53**	**80**
	350M- SIG W	55	97	98	**83**	95	97	95	**96**	88	80	89	**86**	79	9	60	**49**	**79**
400 Meter	400M-WSP	63	97	99	**86**	95	98	95	**96**	88	80	90	**86**	83	15	69	**56**	**81**
	400M-WDR	63	97	99	**86**	95	98	96	**96**	89	80	90	**86**	83	16	69	**56**	**81**
	400M-SD1	52	97	98	**82**	93	97	94	**95**	87	78	87	**84**	77	8	53	**46**	**77**
	400M-VWS	53	97	98	**83**	94	97	95	**95**	88	79	89	**85**	80	11	57	**49**	**78**
	400M- SIG W	52	97	98	**82**	93	97	95	**95**	87	78	87	**84**	77	8	53	**46**	**77**
450 Meter	450M-WSP	52	97	99	**83**	94	97	93	**95**	86	73	88	**82**	80	14	63	**52**	**78**
	450M-WDR	52	97	99	**83**	94	97	95	**95**	88	80	88	**85**	80	14	63	**52**	**79**
	450M-SD1	46	97	98	**80**	92	95	92	**93**	84	69	83	**79**	76	6	42	**41**	**73**
	450M-VWS	47	97	98	**81**	93	96	93	**94**	85	71	86	**81**	78	11	44	**44**	**75**
	450M- SIG W	46	97	98	**80**	92	95	92	**93**	84	69	83	**79**	76	7	41	**41**	**73**
500 Meter	500M-WSP	52	96	98	**82**	92	95	90	**92**	78	74	82	**78**	76	9	42	**42**	**74**
	500M-WDR	52	96	98	**82**	92	95	92	**93**	85	74	82	**80**	76	8	42	**42**	**74**
	500M-SD1	45	95	98	**79**	90	93	87	**90**	75	71	77	**74**	72	3	28	**34**	**70**
	500M-VWS	46	95	98	**80**	91	94	89	**91**	77	75	80	**77**	73	6	29	**36**	**71**
	500M- SIG W	45	95	98	**79**	90	93	88	**90**	76	73	77	**75**	72	3	27	**34**	**70**

The SODAR data capture was reduced (lower range of values) during certain portions of the measurement period due to natural events and noise interference issues. In the middle of April, 2012, a severe rain event damaged the system, resulting in data captures below 90% for the month. Components of the SODAR system were replaced on April 19, which resulted in a marked improvement in the data capture for each parameter. Other periods during portions of January-February 2013 had some reductions in data capture attributed to new building construction in the area, likely causing noise interference. This issue was finally resolved in early March 2013 by a combination of rotating the SODAR antenna table and other system adjustments.

3.5 Total System Data Capture

The 2012 monitoring plan reviewed by TDEC and EPA Region 4 had the following language to describe the acceptability of each hour's meteorological data for modeling purposes:

"The following criteria will be applied to determine whether an hour of the on-site data is counted as available for purpose of data capture:

- Wind direction, wind speed, and temperature must each be available for a given hour. These variables are used in the meteorological pre-processor to compute the atmospheric stability and other related micrometeorological parameters.
- Each of these parameters must be present from at least one of the three tower levels (10, 50, or 100 meters) or from the 50-m and/or 100-m SODAR levels; they need not be all present from the same level.
- If the SODAR is reporting missing data, but at least one tower level is reporting, then that hour is still acceptable."

Based upon these criteria, the meteorological monitoring program has easily met the 90% data availability for modeling purposes, as shown in Table 3-3. In fact, the meteorological tower had 3 levels of wind and temperature available nearly 100% of the time, and had supplemental SODAR data at four additional levels (up to 300 m) at least 85% of the time. Given the completeness of the meteorological tower data, the overall data coverage for the weather station was at or near 99+% per quarter for the meteorological parameters processed for the AERMOD modeling. Data from the 50-m and 100-m levels of the SODAR were not used in the modeling, but were used in performance testing of the SODAR against the meteorological tower.

Table 3-3: Overall Data Capture Summary by Quarter for Model Input with Onsite Meteorological Data

	Apr[1] 2012	May 2012	Jun 2012	1st Qtr	Jul 2012	Aug 2012	Sep 2012	2rd Qtr
% hours with data available for modeling	99.8	100.0	100.0	99.9	100.0	100.0	99.8	99.9

	Oct 2012	Nov 2012	Dec 2012	3th Qtr	Jan 2013	Feb 2013	Mar 2013	4th Qtr	Cum Avg.
% hours with data available for modeling	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Note: only four hours were missing over the entire year (two hours each in April and September, 2012) due to tower calibration activities.

4.0 Processing of Site-Specific Meteorological Data for AERMET

4.1 Field Data Used for AERMOD Evaluation

To prepare the on-site meteorological data for model input, the raw data needed to be extracted and formatted for use in the AERMET (version 14134) pre-processor. There are two separate sets of data. Meteorological measurements taken at the 100-m tower were made at 4 levels: 2 m, 10 m, 50 m, and 100 m. A nearby SODAR collected upper level data at 50-m increments up to the 500-700 m range. For the modeling, validated hourly[10] data were used from the SODAR from the 150-m level up to the 700-m level[11]. The sparseness of data above 700 m restricted its use in the modeling.

For wind data, the 1-minute-averaged winds from the tower at the 10-m, 50-m, and 100-m levels were extracted for use in the "AERMINUTE-all" preprocessor written for this project in order to provide an averaging procedure consistent with EPA's AERMINUTE meteorological processor. AERMINUTE-all is an AECOM-modified version of the EPA's AERMINUTE program, which uses National Weather Service (NWS) Automated Surface Observing System (ASOS) station data to calculate the hourly wind data based on the ASOS 1-minute data. However, since the ASOS stations' minute data is in fact recorded as a 2-minute running average, AERMINUTE takes every other minute's values to use in the hourly averages, thus limiting the maximum number of valid records per hour to 30. Since this 2-minute running average issue does not exist in the on-site data, AERMINUTE-all uses all (up to 60) of the valid, non-calm minute averages in the hourly calculations. The hourly-averaged wind data for these levels is used as a QA check to assess the performance of the averaging conducted in AERMINUTE-all.

For modeling purposes, no replacements of calms were done on the meteorological tower winds that recorded speeds below the wind vane starting threshold level of 1 mph. The AERMET and AERMINUTE-all processor take into account winds that are below a threshold value consistent with the instrument characteristics. For values of the standard deviation of vertical velocity (sigma-w) that were below ta value of 0.1 m/s, those values were set to missing[12].

Table 4-1 summarizes the data needed for the AERMOD model as well as the averaging period for each variable. Figure 4-1 details the processing of the raw data into AERMOD-ready surface and upper-air files. A more technical description of the procedures used as well as the AECOM-developed software for expediting the data pre-processing can be found in the modeling archive.

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[10] Starting in September 2012, 15-minute sub-hourly data were also collected for a few months.

[11] After the change in September, 2012 to sub-hourly data, SODAR data was archived up to the 500-m level.

[12] The starting speed of the vertical wind vane was 0.3 m/s. As per guidance in the SCIPUFF Technical Documentation, 2008. "A typical value for the vertical velocity variance, (sigma-w)^2, is 0.01m^2s^{-2} and a typical vertical length scale, lambda-V, is 10m. We suggest using these values for all locations above the boundary layer." This implies a minimum sigma-w of 0.1 m/s. (p 194).

Table 4-1: Raw On-site Data Used in the Modeling

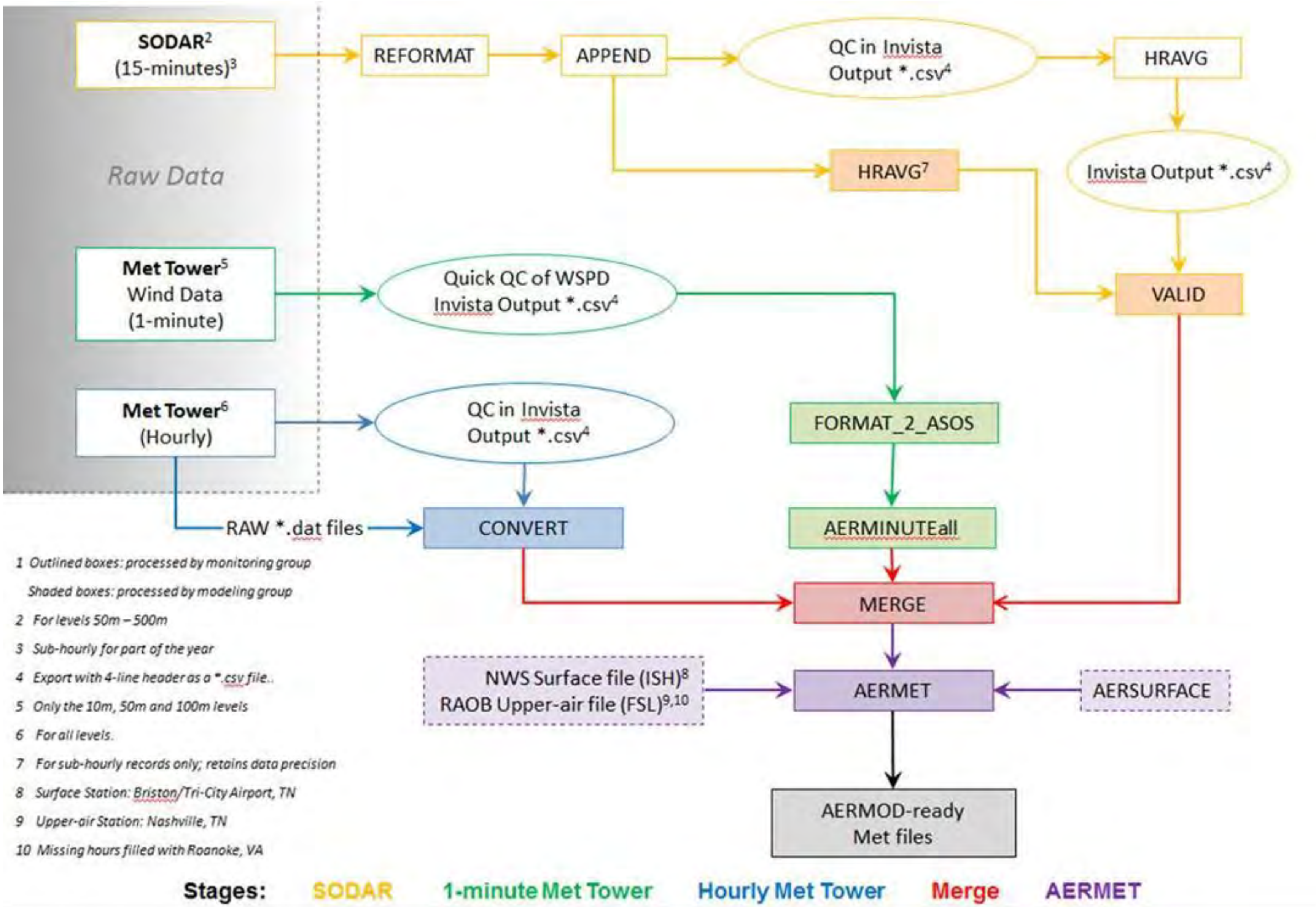
Levels	MET TOWER: Hourly				
2 m	Pressure	Insolation	Temperature		
10, 50 and 100 m	Horiz. Wspd.	Wind Dir.	Sigma-theta	Sigma-w	Temp
Levels	**MET TOWER: Minute**				
10, 50 and 100 m	Horiz. Wspd.	Wind Dir.			
Levels	**SODAR: Sub-hourly & Hourly**				
Every 50 m from 150 – 700 m	Horiz. Wspd.	Wind Dir.	Sigma-w		

4.2 Model Information

The air dispersion modeling was performed using EPA's preferred air dispersion model AERMOD (version 14134). AERMOD is a steady-state plume model that calculates air dispersion based on planetary boundary layer turbulence structure and scaling concepts. AERMOD is listed as a recommended model in Appendix W of 40 CFR Part 51 for determining compliance with National Ambient Air Quality Standards and other regulatory requirements. Supporting EPA processors utilized in this application include: the downwash processor BPIP (version 04274); the terrain processor AERMAP (version 11103); and the meteorological processors AERSURFACE (version 13016) and AERMET (version 14134).

The meteorological data reported by the 100-m tower are scalar averages, but those from the SODAR are vector averages. Due to the large percentage of hours for which SODAR data was available, the VECTORWS option was selected in AERMOD.

Figure 4-1: On-site Data Processing Flowchart[1]



4.3 Meteorological Processing: Surface Characteristics

A full year of the on-site meteorological data was processed with AERMET, the meteorological preprocessor for AERMOD, which is consistent with guidance stated in 9.3.1.2 of 40 CFR Part 51, Appendix W (EPA modeling guidelines). The meteorological data required for input to AERMOD was created with the latest version of AERMET (14134). AERMET creates two output files for input to AERMOD:

- SURFACE: a file with boundary layer parameters such as sensible heat flux, surface friction velocity, convective velocity scale, vertical potential temperature gradient in the 500-meter layer above the planetary boundary layer, and convective and mechanical mixing heights. Also provided are values of Monin-Obukhov length, surface roughness, albedo, Bowen ratio, wind speed, wind direction, temperature, and heights at which measurements were taken.

- PROFILE: a file containing multi-level meteorological data with wind speed, wind direction, temperature, sigma-theta (σ_θ) and sigma-w (σ_w) when such data are available. For this application, the file contains data from several levels on the tower (2, 10, 50 and 100 m) and SODAR (from 150 m through 700 m, at 50-m increments).

AERMET requires specification of site characteristics including surface roughness (z_o), albedo (r), and Bowen ratio (B_o). These parameters were developed according to the guidance provided by EPA in the AERMOD Implementation Guide (AIG)[13].

The AIG provides the following recommendations for determining the site characteristics:

1. The determination of the surface roughness length should be based on an inverse distance weighted geometric mean for a default upwind distance of 1 kilometer relative to the measurement site. Surface roughness length may be varied by sector to account for variations in land cover near the measurement site; however, the sector widths should be no smaller than 30 degrees.

2. The determination of the Bowen ratio should be based on a simple un-weighted geometric mean (i.e., no direction or distance dependency) for a representative domain, with a default domain defined by a 10-km by 10-km region centered on the measurement site.

3. The determination of the albedo should be based on a simple un-weighted arithmetic mean (i.e., no direction or distance dependency) for the same representative domain as defined for Bowen ratio, with a default domain defined by a 10-km by 10-km region centered on the measurement site.

The AIG recommends that the surface characteristics be determined based on digitized land cover data. EPA has developed a tool called AERSURFACE that can be used to determine the site characteristics based on digitized land cover data in accordance with the recommendations from the

[13] Available in the AERMOD documentation at http://www.epa.gov/ttn/scram/dispersion_prefrec.htm#aermod.

AIG discussed above. AERSURFACE incorporates look-up tables of representative surface characteristic values by land cover category and seasonal category. AERSURFACE was applied with the instructions provided in the AERSURFACE User's Guide.

The latest version of AERSURFACE (Version 13016) supports the use of land cover data from the USGS National Land Cover Data 1992 archives[14] (NLCD92). The NLCD92 archive provides data at a spatial resolution of 30 meters based upon a 21-category classification scheme applied over the continental U.S. The AIG recommends that the surface characteristics be determined based on the land use surrounding the site where the surface meteorological data were collected.

As recommended in the AIG for surface roughness, the 1-km radius circular area centered at the meteorological station site was divided into 12 sectors for this analysis (see Figure 4-2).

In AERSURFACE, the various land cover categories are linked to a set of seasonal surface characteristics. As such, AERSURFACE requires specification of the seasonal category for each month of the year. The following five seasonal categories are supported by AERSURFACE, with the applicable months of the year specified for this site.

1. Midsummer with lush vegetation (June-August).
2. Autumn with un-harvested cropland (September- November).
3. Late autumn after frost and harvest, or winter with no snow (December, January, and February).
4. Winter with continuous snow on ground (none; based on the Tri-City Regional Airport record for April, 2012 – March, 2013).
5. Transitional spring with partial green coverage or short annuals (March-May).

For Bowen ratio, the land use values are linked to three categories of surface moisture corresponding to average, wet, and dry conditions. The surface moisture condition for the site may vary depending on the meteorological data period for which the surface characteristics will be applied. AERSURFACE applies the surface moisture condition for the entire data period. Therefore, if the surface moisture condition varies significantly across the data period, then AERSURFACE can be applied multiple times to account for those variations. As recommended in the AERSURFACE User's Guide, the surface moisture condition for each month was determined by comparing the on-site precipitation for the period of data to be processed to the 30-year climatological record (Tri-City Regional Airport), selecting "wet" conditions if precipitation is in the upper 30th percentile, "dry" conditions if precipitation is in the lower 30th percentile, and "average" conditions if precipitation is in the middle 40th percentile. The 30-year precipitation data set used in this modeling was taken from the National Climatic Data Center. The monthly designations of surface moisture input to AERSURFACE are summarized in Table 4-1.

[14] http://edcftp.cr.usgs.gov/pub/data/landcover/states/

Table 4-2: Bowen Ratio Categories for the On-site Meteorological Tower

Month	Bowen Ratio Category	
	2012	2013
April	Average	--
May	Dry	--
June	Dry	--
July	Wet	--
August	Dry	--
September	Wet	--
October	Average	--
November	Dry	--
December	Dry	--
January	--	Wet
February	--	Dry
March	--	Average

4.4 Meteorological Processing: AERMET

The processed on-site 12-level meteorological data for the merged meteorological tower (levels: 2 m, 10 m, 50 m and 100 m) and SODAR (levels: 150 m – 500 m, at 50-m increments) was entered into the stage 1 AERMET input file along with concurrent NWS surface data from the Tri-City Regional Airport National Weather Station (13877) and upper air data from Nashville, TN (13897).

The Tri-City Regional Airport is located approximately 8.5 miles east, southeast of the facility. Integrated Surface Hourly (ISH) surface data in for the April, 2012 – March, 2013 period were downloaded from the National Climate Data Center (NCDC)[15]. The Nashville airport is located 200 miles west of Kingsport and has mean mixing heights that are comparable to this location. Upper air data was downloaded from the NOAA radiosonde observation (RAOB) website[16]. Three missing upper air 12Z hours were filled with concurrent data from the nearby Roanoke, VA upper air station (noted in a README file in the accompanying modeling archive).

The meteorological data was processed using the AERMOD meteorological preprocessor AERMET (version 14134).

The threshold wind speed for the on-site data was set at 0.44704 m/s (1 mph). In the stage 3 input, no NWS substitutions were performed for any hours with missing on-site wind data (which was not an issue given the high data coverage of the meteorological tower). Two sets of meteorological data were produced. For the default AERMET/AERMOD testing, AERMET was processed with no special option (aside from VECTORWS mentioned in section 4.2).

For a sense of the bulk wind flow near plume height, the 100-m wind rose in Figure 4-3 shows the percentage of time wind blew from each direction for the April, 2012 through March, 2013 period.

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[15] ftp://ftp.ncdc.noaa.gov/pub/data/noaa

[16] http://www.esrl.noaa.gov/raobs/

Figure 4-2: Land Use, 1 km Around On-site Meteorological Station from National Land Cover Dataset

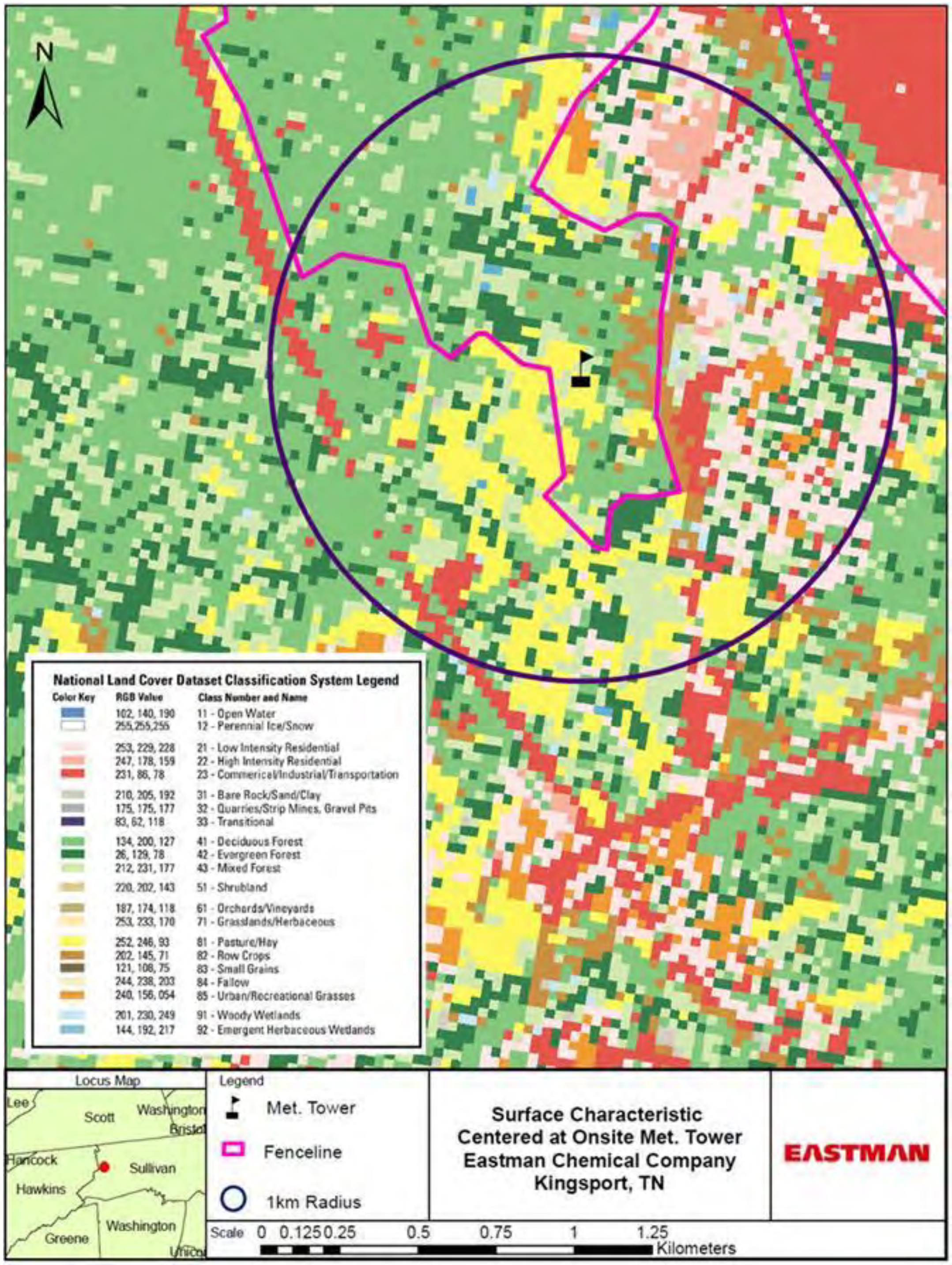
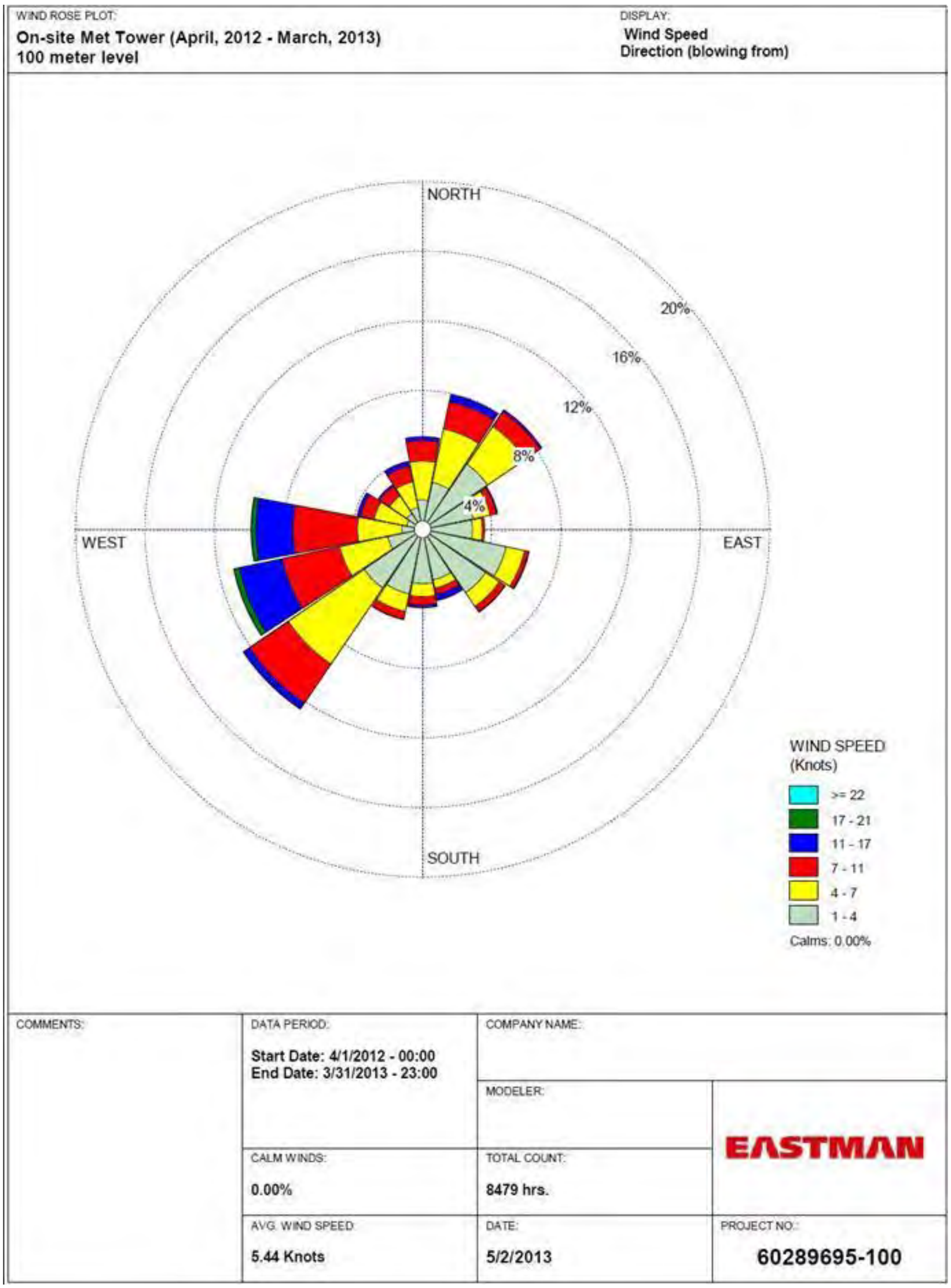


Figure 4-3: Wind Rose for 100-m On-site Meteorological Tower; Kingsport, TN



5.0 Procedures for Model Evaluation

AERMOD was run with hourly emissions and exhaust parameter data supplied by Eastman and with the hourly meteorological data processed as described in Section 4. Initial modeling was conducted with default modeling options to determine whether AERMOD has relatively unbiased predictions at the three monitors that operated during the entire period of the meteorological monitoring program. Predictions were made at these three monitoring sites (Meadowview, Ross N. Robinson, and Skyland Drive) and were compared to observations using the evaluation metrics described below. These evaluation metrics were incorporated into presentations made to TDEC and EPA in December 2012 and March 2013.

5.1 Performance Evaluation Metrics Used

The model evaluation results are reported using metrics that address four basic areas.

- A key operational metric is tied to the form of the 1-hour SO_2 NAAQS is the "design concentration" (99th percentile of the peak daily 1-hour maximum values). This tabulated statistic was developed for the three monitors for the observations and model predictions at each individual monitor.

- Time series plots of the observed and predicted daily maximum 1-hour SO_2 concentrations were also developed; see Figure 7-5 for examples. While the tabulation of the design concentration provides a comparison of just one value for the predictions and observations, the time series plot provides a comparison for the entire period evaluated. The plots show the relative frequency and magnitude of the concentration predictions and observations. Our review of these plots result in somewhat qualitative, but informative, findings regarding the performance of each model and also present seasonal distributions of the concentration patterns for both observations and predictions.

- Operational performance of models for predicting compliance with air quality regulations, especially those involving a peak or near-peak value at some unspecified time and location, can be assessed with quantile-quantile (Q-Q) plots[17]. Q-Q plots (see figures in Section 7 for examples) are created by sorting by rank the predicted and the observed concentrations from a set of predictions initially paired in time and space. The sorted list of predicted concentrations is then plotted by rank against the observed concentrations, also sorted by rank. These concentration pairs are no longer paired in time, but we have retained the location pairing in this evaluation study. Such plots are useful for answering the question, "Over a period of time evaluated, does the distribution of the model predictions match those of observations?" Scatterplots, which use data paired in time, would provide a stricter test, answering the question: "At a given time and place, does the magnitude of the model prediction match the observation?" However, it is the experience of model developers[18,19] that wind direction uncertainties can and do

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[17] Chambers, J. M., Cleveland, W. S., Kleiner, B., and Tukey, P. A. 1983. Chapter 3: Comparing Data Distributions. Graphical Methods for Data Analysis. (Bell Laboratories). Wadsworth International Group and Duxbury Press.

[18] Weil J.C, Sykes and Venkatram A. 1992. Evaluating air-quality models: Review and outlook. J. Appl. Met., 31, p 1121-1144.

cause disappointing scatterplot results from what are otherwise well-performing dispersion models. Therefore, the Q-Q plot instead of the scatterplot is a more pragmatic procedure for demonstrating model performance of applied models. Venkatram[20] makes a cogent argument for the use of Q-Q plots for evaluating regulatory models. Quantile-quantile (Q-Q) plots of the ranked daily maximum 1-hour SO_2 concentrations for predictions and observations are useful. A "perfect" model would have all points on the central diagonal (45-degree) line.

- Lists of the meteorological conditions and hours/dates of the top several predictions and observations provide an indication as to whether these conditions are consistent between the model and monitoring data. For example, if the peak observed concentrations generally occur during daytime hours, we would expect that a well-performing model would indicate that the peak predictions are during the daytime as well. Another meteorological variable of interest is the wind speed magnitudes associated with observations and predictions. It would be expected, for example, that if the wind speeds associated with peak observations are low, then the modeled peak predicted hours would have the same characteristics.

5.2 Tolerance Range for Unbiased Model Results

One issue to keep in mind regarding SO_2 monitored observations, is that they can be biased up to 10% and be acceptable. This fact is related to the tolerance in the EPA procedures[21] associated with quality control checks and span checks. Therefore, even ignoring uncertainties in model input parameters that can also lead to modeling uncertainties, just the uncertainty in measurements indicate that modeled-to-monitored ratios between 0.9 and 1.1 should be considered as unbiased.

[19] Liu, M. K., and G. E. Moore. 1984. Diagnostic validation of plume models at a plains site. EPRI Report No. EA-3077, Research Project 1616-9, Electric Power Research Institute, Palo Alto, CA.

[20] Venkatram, A., R. W. Brode, A. J. Cimorelli, J. T. Lee, R. J. Paine, S. G. Perry, W. D. Peters, J. C. Weil, and R. B. Wilson. 2001. A complex terrain dispersion model for regulatory applications. *Atmos.Environ.,* 35, 4211-4221.

[21] Quality Assurance Handbook for Air Pollution Measurement Systems, Volume II, Ambient Air Quality Monitoring Program, 2013, available at http://www.epa.gov/ttnamti1/files/ambient/pm25/qa/QA-Handbook-Vol-II.pdf. (Table 10-3 and Appendix D, page 13).

6.0 Determination of Background Concentrations

To account for the impact of sources other than Eastman, it is necessary to include the contributions of any identified nearby SO_2 sources as well as distant sources that would have a relatively uniform concentration impact over the nonattainment area. The discussion in Section 2.4 establishes that there are no nearby sources of SO_2 that should be included in the modeling.

The procedure we used to quantify the regional background concentration was to use data from the available Eastman monitors and to construct an hourly sequence of concentrations for an idealized background monitor that consists of the lowest concentration measured among the monitors for each hour. This step reduces the chances of double-counting the impacts from the Eastman sources and the monitor. However, a conservatively high background was selected from this hourly sequence by using the Tier 2 approach of the 99th percentile value by hour and season as described in the March 1, 2011 EPA guidance[22]. The seasonal by hour of the day ambient background value was processed within the model using the BACKGRND SEASHR keyword in the source card.

Additional filters on the data to set aside hours for which all monitors may have been impacted by Eastman plant emissions (due to stagnation or recirculation) were as follows:

- A downwind analysis of all meteorological levels up to 400 m was performed to eliminate plant impacts (wind directions within +/- 45 degrees of a monitor eliminated that monitor for the given hour).
- Rare hours with high impacts (> 30 µg/m^3) at all monitors were excluded from consideration for the 99th percentile background.
- After the downwind and high-impact considerations, the hourly values were screened for the lowest remaining observations among the valid monitor records for each hour.
- The method prescribed by the 2011 EPA guidance prescribes that for 1-hour SO_2, the 99th percentile for each season for each hour (i.e. the 2nd High) were selected for the lookup table.
- Hour 4 was typically a calibration hour in the monitoring network, so data from hours 3 and 5 were used to interpolate values for the lookup table.

Figure 6-1 shows the resultant seasonal values. Table 6-1 tabulates the same 96 values from Figure 6-1 for the modeling.

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[22] This guidance is available at http://www.epa.gov/ttn/scram/guidance/clarification/Additional_Clarifications_AppendixW_Hourly-NO2-NAAQS_FINAL_03-01-2011.pdf.

Figure 6-1: Seasonal by Hour of Day Ambient Background Values for Kingsport

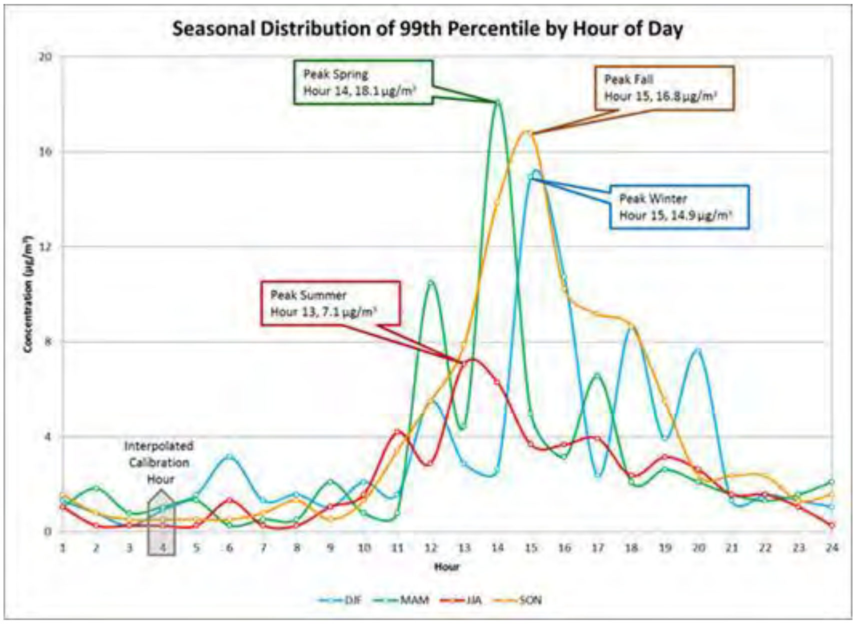

Table 6-1: Lookup Table for Each Season by Hour of Day

Hour	DJF	MAM	JJA	SON
1	1.31	1.05	1.05	1.57
2	0.79	1.83	0.26	0.79
3	0.26	0.79	0.26	0.52
4	0.92	1.05	0.26	0.52
5	1.57	1.31	0.26	0.52
6	3.14	0.26	1.31	0.52
7	1.31	0.52	0.26	0.79
8	1.57	0.52	0.26	1.31
9	1.05	2.1	1.05	0.52
10	2.1	0.79	1.57	1.31
11	1.57	0.79	4.19	3.41
12	5.5	10.48	2.88	5.5
13	2.88	4.45	7.07	7.86
14	2.62	18.08	6.29	13.89
15	14.93	4.98	3.67	16.77
16	10.74	3.14	3.67	10.22
17	2.36	6.55	3.93	9.17
18	8.65	2.1	2.36	8.65
19	3.93	2.62	3.14	5.5
20	7.6	2.1	2.62	2.36
21	1.31	1.57	1.57	2.36
22	1.57	1.31	1.57	2.36
23	1.31	1.57	1.05	1.31
24	1.05	2.1	0.26	1.57

7.0 Evaluation Results for Default AERMOD Model

AERMET/AERMOD version 14134 as run in regulatory default mode was evaluated with Eastman hourly SO_2 emissions and stack exhaust data for the period April 1, 2012 through March 31, 2013 for three monitoring sites: Ross N Robinson, Skyland Drive, and Meadowview. This section describes the processing of the receptor and building downwash information; the previous section detailed the processing of the on-site meteorological data. The results of the evaluation for the default AERMOD model are presented using the evaluation metrics described in Section 5.

7.1 Receptor Processing

The application of AERMOD requires characterization of the local (within 3 kilometers) dispersion environment as either urban or rural, based on an EPA-recommended procedure that characterizes an area by prevalent land use. This land use approach classifies an area according to 12 land use types. In this scheme, areas of industrial, commercial, and compact residential land use are designated urban. According to EPA modeling guidelines, if more than 50 percent of an area within a 3-km radius of the proposed facility is classified as rural, then rural dispersion coefficients are to be used in the dispersion modeling analysis. Conversely, if more than 50% of the area is urban, urban dispersion coefficients are used. Visual inspection of the 3-km area surrounding the Eastman facility location shows the area is rural (see Figure 7-1).

Model receptors were placed at the three monitoring locations. Terrain elevations were developed from the National Elevation Dataset (NED) acquired from USGS[23], using the EPA's terrain processor, AERMAP (version 11103).

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[23] http://seamless.usgs.gov/index.php

Figure 7-1: Aerial of 3-km Radius around the Facility Center of Eastman Chemical Company

7.2 Building Downwash Processing

Good engineering practice (GEP) stack height is defined as the stack height necessary to ensure that emissions from the stack do not result in excessive concentrations of any air pollutant as a result of atmospheric downwash, wakes or eddy effects created by the source, nearby structures or terrain features.

A GEP stack height analysis was performed for the hazardous waste combustion unit stacks in accordance with EPA's stack height guidelines (EPA, 1985). Per the guidelines, the physical GEP height, (H_{GEP}), is determined from the dimensions of all buildings which are within the region of influence using the following equation:

$$H_{GEP} = H_B + 1.5L$$

where:

H_B = height of the structure within 5L of the stack which maximizes H_{GEP}, and

L = lesser dimension (height or projected width) of the structure.

For a squat structure, i.e., height less than projected width, the formula reduces to:

$$H_{GEP} = 2.5H_B$$

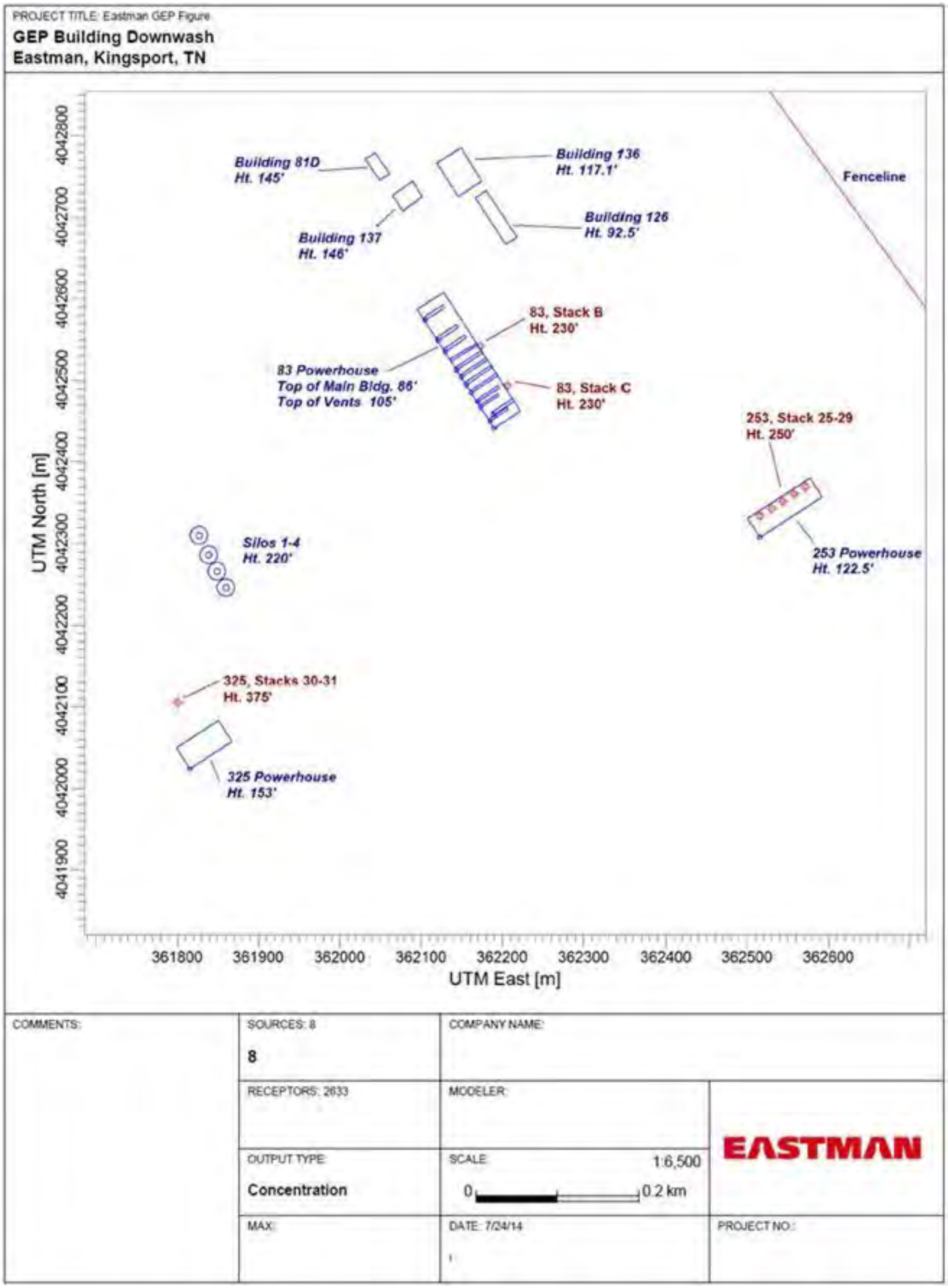
In the absence of influencing structures, a "default" GEP stack height is credited up to 65 meters.

A summary of the GEP stack height analyses is presented Table 7-1. The GEP formula stack heights for all the sources are higher than their respective stack heights. Therefore, emissions are potentially subject to building downwash and wind direction-specific building dimensions developed with the EPA's Building Profile Input Processor (BPIP-PRIME) were input to AERMOD. The BPIP input and output files are provided in the modeling archive. The locations and dimensions of the buildings/structures relative to the exhaust stacks are depicted in Figure 7-2.

Table 7-1: Summary of GEP Analysis

Emission Source	Model Source Name	Stack Height (m)	Controlling Buildings / Structures	Building Height (m)	Projected Width (m)	GEP Formula Height (m)
253 Powerhouse Sources	253_25 – 253_29	76.2	253 Powerhouse	37.3	116.8	181.2
325, Stacks 30-31	325_3031	114.3	Silos	67.1	69.0	149.1
B-83 Powerhouse Stacks 18-22	83_1822	70.1	B-83 Powerhouse (top of exhaust ducts)	32.0	177.2	79.9
B-83 Powerhouse Stacks 23-24	83_2324	70.1	Building 81D	44.2	177.9	113.7

Figure 7-2: GEP Building Downwash for Eastman Chemical



7.3 Evaluation Results for Default AERMOD

AERMOD was run using the default meteorological and modeling options in both AERMET and AERMOD, respectively. As noted, on-site meteorological data were processed up to 500 m to best capture the conditions observed by the SO_2 monitors. The hourly seasonal ambient background value was included in these model runs. For comparison to observed monitor data, three separate AERMOD runs were performed on a single receptor situated and processed at each the three monitors (Figure 3-1). Furthermore, to better estimate the actual impacts, hourly emission data (including stack temperature and exit velocity) for all eight sources were included in the modeling. The modeling and observation periods were coincidental, from April 1, 2012 through March 31, 2013.

The observed and predicted design concentrations for 1-hour SO_2 are tabulated in Table 7-2. Figure 7-3 plots these results, but also includes the model-to-monitor ratios for each site. As noted in section 5.2, an ideal unbiased model would produce values between 0.9 to 1.1. For the default case, the ratio values range between 1.8 to 2.7 (over-prediction). From a comparison of these three pairs of design values, it appears that AERMOD version 14134 run using the default options is producing unrealistic over-predictions. Examining the year-long time series of the daily maxima for each monitor, (Figures 7-4, a-c), we find that the default AERMOD model (in red) is producing an exaggerated and highly variable sequence of ground concentrations compared to the observed values (in blue), particularly at the elevated terrain of Skyland Drive.

The Q-Q plots (Figures 7-5, a-c) for each monitor also shows this over-prediction, with all ranked values shown. For the flat terrain monitors (Meadowview and Ross N. Robinson), the ranked predictions are about twice the observed ranked values. The performance of the default AERMOD is even worse at the elevated terrain Skyland Drive monitor (Figure 7-5c). The over-prediction of the model approaches a factor of 3.

For the flat terrain monitors, the top 10 observations occur during the daytime hours with relatively low wind speeds and convective mixing heights of at least 400 m. All but one of the predicted top 10 flat terrain concentrations occur during the daytime, but all occur in low wind surface conditions. Additionally, the convective mixing heights were generally below 400 m, with most occurring below 250 m. For Skyland Drive, the top 10 observations were mostly during daytime hours, with 2 nighttime hours also included, in low to moderate wind speeds. The predicted top 10 values, on the other hand, all occurred at night or early morning in low wind speeds conditions.

Table 7-2: Comparison of 1-hour SO_2 Design Concentrations, Observed vs. Predicted (for the Default AERMET/AERMOD, version 14134)

April, 2012 – March, 2013	H4H Concentrations ($\mu g/m^3$)	
Monitor	**Observed**	**Predicted (Default)**
Meadowview	359.5	730.5
Ross N. Robinson	428.1	776.0
Skyland Dr.	406.6	1102.8

Figure 7-3: Comparison of Observed vs. Predicted 1-hour SO2 Design Concentrations for the Default AERMET/AERMOD, version 14134

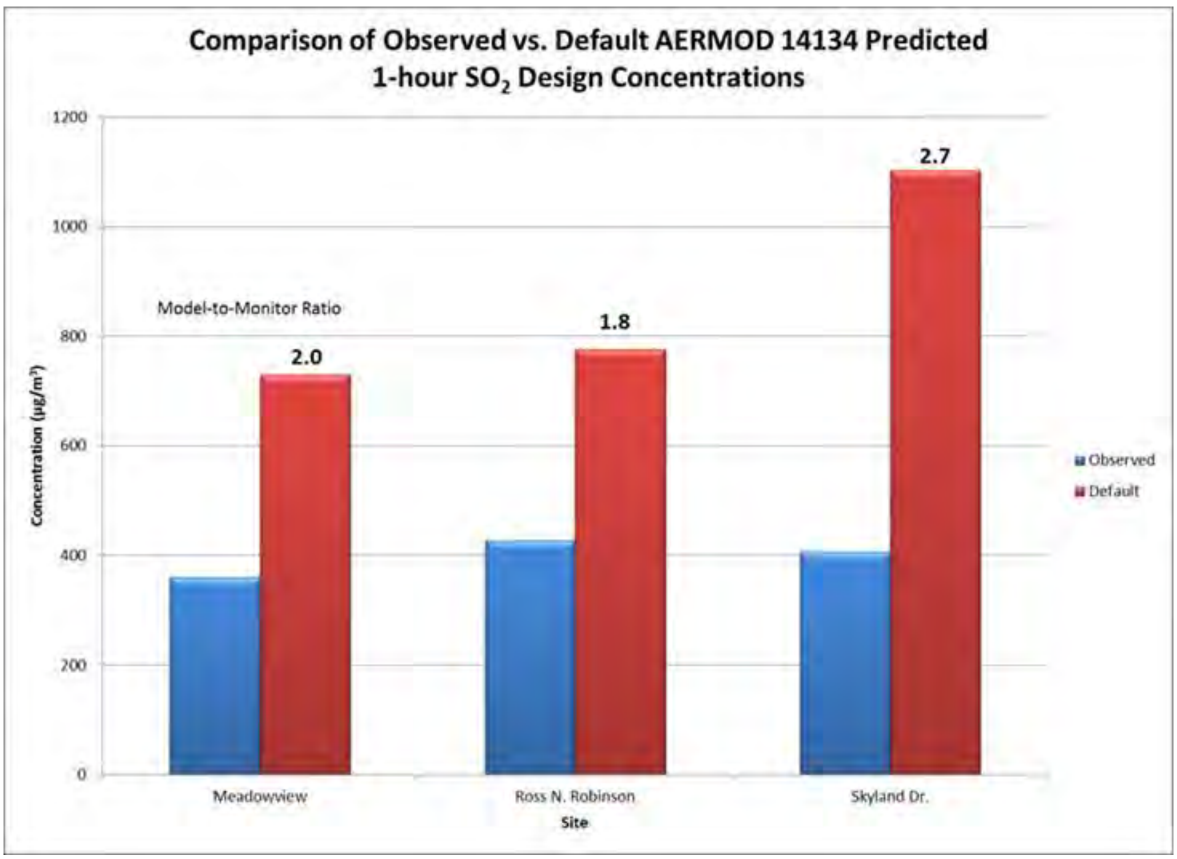


Figure 7-4 (a-c): Time series of Daily Maxima of Observed (Blue) vs. Predicted (Red) for Default AERMOD, at (a) Meadowview, (b) Ross N. Robinson, (c) Skyland Drive

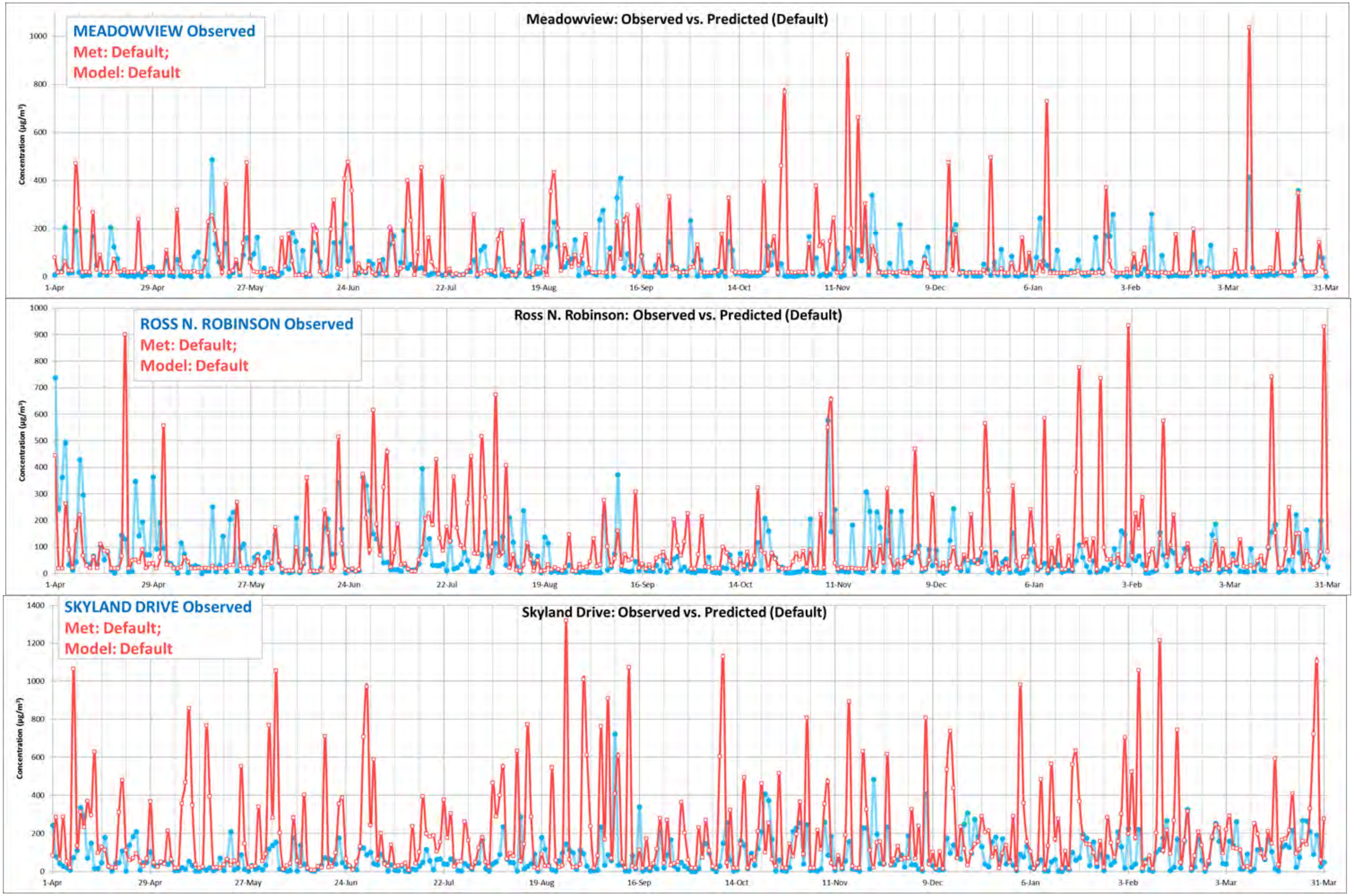
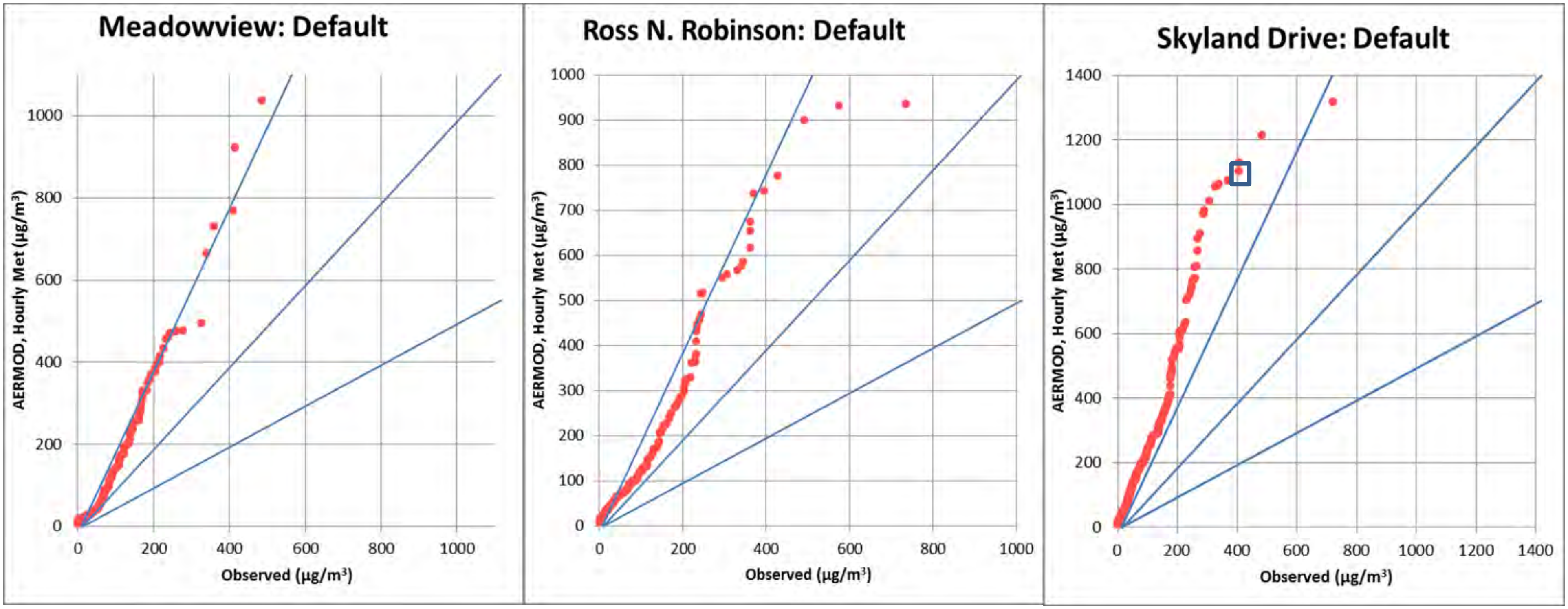


Figure 7-5 (a-c): Q-Q Plots for Observed vs. Predicted Default AERMET/AERMOD version 14134



(a) (b) (c)

Notes:

[1]The upper diagonal shows the two-fold model over-prediction and the lower diagonal, the two-fold under-prediction. The central diagonal is the 1:1 correlation line.

[2] The predicted model concentrations include the seasonal by hour-of-day background value.

[3] The boxed value represents the design concentration (i.e. the High-4th-High)

8.0 Formulation of Eastman's Site-Specific Dispersion Model

The need for a nearly unbiased site-specific dispersion model for the resolution of the Kingsport SO_2 nonattainment area led Eastman to ask AECOM to provide recommendations for enhancements to AERMOD based upon scientifically-justified principles. This section describes the formulation of "EASTMOD", the site-specific dispersion model based upon AERMOD that Eastman proposed to use for its Kingsport, TN facility.

8.1 Provisions for Acceptance of an Alternative Site-Specific Model

Appendix W, EPA's modeling guidance, has provisions for obtaining agency acceptance of an alternative model in the event that the default model is not adequate for the intended purpose. The applicable Appendix W language (Section 3.2.2(b)(2)) is provided below with *italics* applied to the specific case of interest here.

> 3.2.2 Recommendations
>
> a. Determination of acceptability of a model is a Regional Office responsibility. Where the Regional Administrator finds that an alternative model is more appropriate than a preferred model, that model may be used subject to the recommendations of this subsection. This finding will normally result from a determination that (1) a preferred air quality model is not appropriate for the particular application; or (2) a more appropriate model or analytical procedure is available and applicable.
>
> b. An alternative model should be evaluated from both a theoretical and a performance perspective before it is selected for use. There are three separate conditions under which such a model may normally be approved for use:
>
> > (1) If a demonstration can be made that the model produces concentration estimates equivalent to the estimates obtained using a preferred model;
> >
> > *(2) if a statistical performance evaluation has been conducted using measured air quality data and the results of that evaluation indicate the alternative model performs better for the given application than a comparable model in Appendix A;* or
> >
> > (3) if the preferred model is less appropriate for the specific application, or there is no preferred model. Any one of these three separate conditions may make use of an alternative model acceptable. Some known alternative models that are applicable for selected situations are listed on EPA's SCRAM Internet Web site (subsection 2.3). However, inclusion there does not confer any unique status relative to other alternative models that are being or will be developed in the future.
>
> b. The Regional Office should always be consulted for information and guidance concerning modeling methods and interpretations of modeling guidance, and to ensure that the air quality model user has available the latest most up-to-date policy and procedures. As appropriate, the Regional Office may request assistance from the Model Clearinghouse after an initial evaluation

and decision has been reached concerning the application of a model, analytical technique or data base in a particular regulatory action.

For this application using Appendix W Section 3.2.2(b)(2), we provide a description of the proposed EASTMOD model with citations to applicable technical references in this section. In the next section, we provide an evaluation of EASTMOD and compare the evaluation results to AERMOD (default).

8.2 Areas of Enhancement Incorporated into EASTMOD

It is evident from the evaluation results of AERMOD (default) that peak predictions occur in light wind conditions for the three monitors included in the Eastman evaluation. AECOM pursued model enhancements in two areas:

- Low wind speed improvements already being considered by EPA and implemented as beta options in AERMOD version 14134 were adopted in EASTMOD, with slight variations and enhancements.
- The merging of plumes from nearby stacks is not accounted for by AERMOD, but is probably occurring at Eastman, especially in light wind conditions.

The formulation of these two areas of enhancement into AERMOD to create the EASTMOD model is described in the following subsections.

8.3 Low Wind Speed Enhancements

In 2005, the EPA promulgated the currently recommended short-range dispersion model, AERMOD, which replaced the Industrial Source Complex (ISC) model as the preferred prediction tool for short-range dispersion applications. Over several years of AERMOD use, it has become apparent to the modeling community that peak predicted concentrations from AERMOD modeling can occur for simulated periods of low wind speeds. A review of the AERMOD evaluation databases noted above would indicate that there was not a significant focus upon data sets featuring low wind speeds.

In 2010, the results of a model evaluation study[24] sponsored by the American Petroleum Institute (API) and the Utility Air Regulatory Group (UARG) were provided to EPA that specifically examined the model's ability to predict under low wind speed stable conditions for near ground-level releases. The 2010 API/UARG sponsored study examined two aspects of the model: (1) the meteorological inputs, as it related to friction velocity (u_*) and (2) the actual dispersion model itself, especially the minimum lateral turbulence (as parameterized using sigma-v) assumed by AERMOD. As part of phase 1 of the study, Paine et al.[15] concluded that evaluation indicated that in low wind conditions, the u_* formulation in AERMOD under-predicts this important planetary boundary layer parameter. The outcomes of this under-prediction in u_* were too low and restrictive mechanical mixing heights, as well as underestimates of the effective dilution wind speed and turbulence in stable conditions. As part of phase 2 of the study, Paine et al.[15] concluded that the minimum sigma-v was too low by at

[24] Paine, R.J., J.A. Connors, and C.D. Szembek. AERMOD Low Wind Speed Evaluation Study: Results and Implementation. Paper 2010-A-631-AWMA, presented at the 103rd Annual Conference, Air & Waste Management Association, Calgary, Alberta, Canada. 2010.

least a factor of 2. These findings were consistent with those of Sykes et al.[25] with applications of SCIPUFF using a minimum sigma-v of 0.5 m/s with good modeling performance and Hanna[26] with reviews of low wind speed databases, who mentions a small turbulence scale sigma-v of 0.5 m/s as a typical value in low winds. A minimum sigma-v of 0.5 m/s in AERMOD (using LOWWIND2) in conjunction with the AERMET low wind speed beta u* option was reported by Paine[27] at the 2014 EPA modeling workshop to provide improved model performance for tall stack releases.

The result of the 2010 API/UARG sponsored study confirmed what the modeling community and EPA suspected, that AERMOD was significantly over-predicting modeled concentrations under low wind speed stable conditions.

EPA implemented improvements[28] to AERMOD similar to those suggested by Paine et al.[15] in its release of versions 12345, 13350, and the current release, 14134. In these releases, EPA implemented a correction to the friction velocity calculation in AERMET and also incorporated changes to the meander fraction calculation and the minimum sigma-v calculation in AERMOD.

Consistent with these available improvements to AERMET and AERMOD, the formulation of EASTMOD applies the following enhancements:

- The AERMET version 14134 with the beta u* option is used. The use of this beta option is consistent with encouraging evaluation results reported by EPA in its presentation[29] on version 13350 and the webinar recording[30] conducted on January 14, 2014.
- AERMOD with the LOWWIND2 option deployed and with a minimum sigma-v averaging 0.5 m/s, but split between 0.6 m/s for stack emissions in stable conditions and 0.4 m/s for emissions in unstable conditions. This implementation required a minor code change to AERMOD version 14134 to implement the stable/unstable “split” in the minimum sigma-v settings.

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[25] Sykes, R.I., S. Parker, D. Henn and B. Chowdhury, 2007: SCIPUFF Version 2.3 Technical Documentation. L-3 Titan Corp, POB 2229, Princeton, NJ 08543, 336 pp.; current SCICHEM documentation is available at http://sourceforge.net/projects/epri-dispersion/.

[26] Hanna, Steven R., 1983: Lateral Turbulence Intensity and Plume Meandering During Stable Conditions. *J. Climate Appl. Meteor.*, **22**, 1424–1430. doi: http://dx.doi.org/10.1175/1520-0450(1983)022<1424:LTIAPM>2.0.CO;2

[27] Presentation is available at http://www.cleanairinfo.com/regionalstatelocalmodelingworkshop/archive/2014/Presentations/Tues/012-aermod%20lowwind%20sensitivity%20and%20evaluation%20update%2023may14.pdf.

[28] See model update bulletins for descriptions of the improvements and technical references at http://www.epa.gov/ttn/scram/models/aermod/aermod_mcb8.txt and http://www.epa.gov/ttn/scram/models/aermod/aermod_mcb9.txt.

[29] Available at http://www.epa.gov/ttn/scram/webinar/AERMOD_13350_Update/AERMOD_System_Update_Webinar_01-14-2014_FINAL.pdf.

[30] Available at https://epa.connectsolutions.com/p166mjb0h19/?launcher=false&fcsContent=true&pbMode=normal.

8.4 Plume Merging Enhancements

The calculation of plume rise from one or more stacks is a key component in determining the downwind impacts associated with that source. Adjacent stacks of similar height and exhaust characteristics exist at numerous facilities, including Eastman for the 83 and 253 boiler complexes. Studies cited below refer to a study of actual field data of plume merging as well as wind tunnel studies that indicate that plumes from adjacent, aligned stacks tend to combine, resulting in a buoyant plume rise greater than that from any one of the individual sources. We find that implementing this concept as a post-processor to an initial run of AERMOD to determine effective hourly stack exhaust characteristics that accounts for the partial plume buoyancy merging will improve model performance.

8.5 Quantifying Enhanced Plume Rise from Adjacent Stacks

The tendency of adjacent stack plumes to merge is a function of several factors, including:

- the separation between the stacks,
- the angle of the wind relative to the stack alignment
- the plume rise for individual stack plumes (associated with individual stack buoyancy flux and meteorological variables such as stack-top wind speed).

In his "Plume Rise and Buoyancy Effects" Chapter 8[31], Briggs refers to the results of wind tunnel studies that indicate the usefulness of a merger parameter, S', to determine the effect of the angle of the wind relative to the stack alignment:

$S' = [\Delta s \sin\Theta] / [L_B^{1/3} (\Delta s \cos\Theta)^{2/3}]$ (Eq. 1)

where

Δs is the average spacing between the aligned stacks
Θ is the wind angle relative to the alignment angle of the adjacent, inline stacks
L_B is the buoyancy length scale = F_B / U^3 (Eq. 2)
F_B is the buoyancy flux = $g\, v_S{}^2 D_S{}^2/4\, (T_S - T_A)/T_S$ (Eq. 3)
U = the wind speed at plume height
V_S = the stack gas exit velocity
T_S = the stack gas temperature
T_A = the ambient temperature
D_S = the stack diameter

By definition, S' is undefined when the wind is exactly normal to the alignment angle, so in practice for that case, an angle of 89.99 is used in our implementation.

Briggs indicated that limited wind tunnel studies using neutral conditions showed that if S' is less than 2.3, then wind tunnel results indicate buoyancy enhancement, while values above 3.3 indicate no enhancement (intermediate values would indicate partial enhancement). However, Anfossi[32]

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[31] Briggs, G. A. Chapter 8 in In *Atmospheric Science and Power Production*. D. Randerson (ed.), DOE/TIC-27601, U.S. Department of Energy.
[32] Anfossi, D., 1985. "Analysis of Plume Rise Data from Five TVA Steam Plants", *Journal of Climate and Applied Meteorology,* vol. 24, pp 1225-1236.

examined multiple cases of plume merging observed in the field at five Tennessee Valley Authority facilities with aligned stacks for both stable and unstable conditions. With this unprecedented large database, he reviewed a wide range of observations taken during the transitional and final plume rise under neutral and stable conditions. Our review of his findings indicates that the threshold values for buoyancy enhancement as a function of wind angle should be such that enhancement likely always occurs for S' less than 5, may not occur for S' above 10, and can be linearly scaled for S' between 5 and 10.

For those wind angles that allow plume merging, a formulation for the buoyancy enhancement accounting for other factors noted above due to the merging of adjacent plumes can be taken from Manins implementation[33] of Briggs formulation:

Buoyancy enhancement factor E = [n+S]/[1+S] (Eq. 4)
where n = the number of stack in the row, and

S is a separation factor = $6 \{[(n-1)\ \Delta s]/[n^{1/3}\ \Delta h]\}^{3/2}$ (Eq. 5)
where Δh is the plume rise for one stack.

8.6 Application of this Procedure

One way to define the parameters necessary for calculating the buoyancy enhancement on an hourly basis involves an initial run of AERMOD for the stacks involved. In order to extract the necessary data (i.e. the hourly and source specific final plume rise and effective wind speed), AECOM has created a modified version of AERMOD (version 14134) that extracts the necessary data using the DISTANCE-DEBUG option. To obtain data such as final plume rise that is used to compute effects of the plume merging process, we conduct this initial run on a 10-km ring of 360 receptors set 1° apart in flat terrain. A post-processor referred to as "AERLIFT" then takes the hourly meteorology and modeling data from the DISTANCE DEBUG output and determines whether plume merging occurs, and by how much (enhancement factor). The maximum enhancement factor applied to the buoyancy flux is the number of stacks in the line. The AERLIFT processor applies the enhancement factor to the original stack velocity and temperature and derives an altered set of parameters that increases the buoyancy flux by the appropriate factor, but preserves the momentum flux. This is done to conservatively apply the enhancement to only the buoyancy component. During stable hours, AERLIFT uses the plume rise directly in equation 5. For added degree of conservativeness, during unstable hours for when the stack top is less than the mixing height, AERLIFT selects the minimum between the final plume rise and the mixing height (which is defined as the maximum of the mechanical and convective mixing heights) for use in equation 5. The recalculated hourly emission parameters are then saved into a separate hourly emission file to be used in a second run of AERMOD.

8.7 Example AERLIFT Case

Consider a line of 4 stacks that are 25 meters apart, each with a height of 70 m and a diameter of 5 m with an east-west alignment. If all 4 sources are active, then under ideal conditions, the effective

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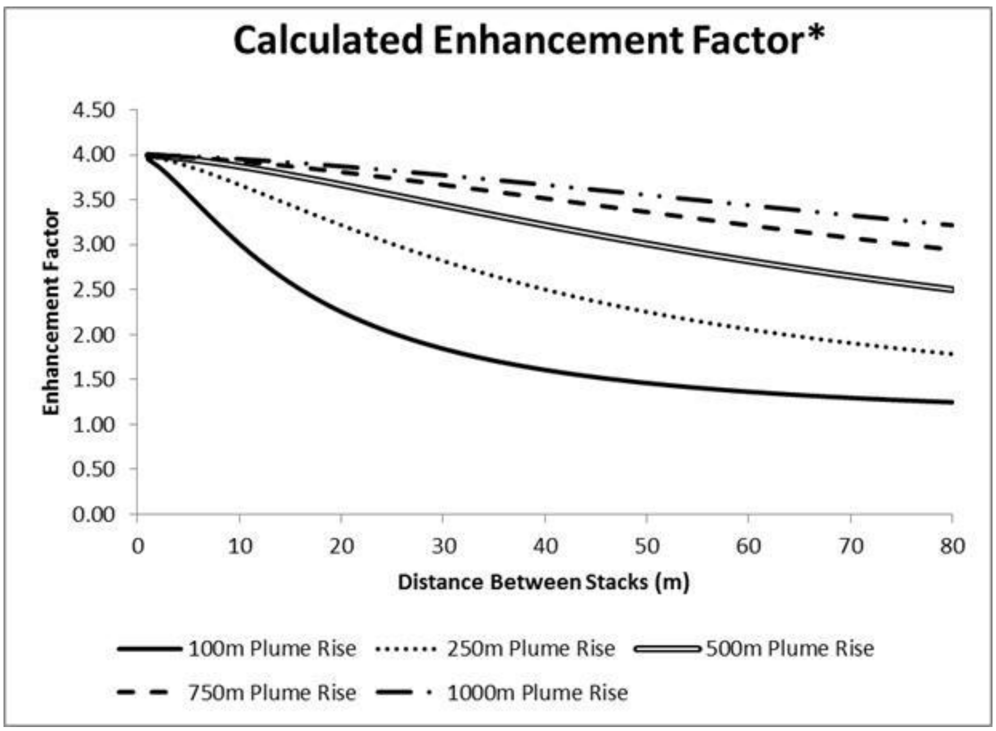
[33] Manins P, Carras J and Williams D, (1992), Plume Rise from Multiple Stacks. Clean Air (Australia). Volume 26, Part 2. pp 65-68.; see http://www.planning.nsw.gov.au/asp/pdf/08_0021_bamarang_ps_stage2_ea_app_c_pt3.pdf

merged buoyancy flux could be scaled up by a factor of 4. If the wind direction is not within 3 degrees of a normal direction (directly from the north or south), there is no effect on merging enhancement due to the wind angle effect; otherwise, there would be a scaled reduction. For most wind angles, Figure 8-1 displays the dependence of the enhancement factor on the distance between the stacks and the plume rise. Note that for very large plume rises (up to 1,000 m) the enhancement factor falls off slowly with increasing stack separation because the magnitude of the plume buoyancy results in substantial plume merging. In contrast, a weaker plume rise of only 100 m would result in a much faster fall-off of plume merging enhancement with stack separation, as shown in the figure. Note that for stacks with no separation, the result is full enhancement, as one would intuitively expect.

Figure 8-1: Illustration of Buoyancy Enhancement for Adjacent Stacks



* for most wind angles; if the wind blows exactly normal to the line of stacks, some reduction in this merging is expected, and the procedure accounts for it through the S' test.

8.8 Evaluation Tests Using EASTMOD

The modeling procedure with EASTMOD is somewhat more complicated than a standard run of AERMOD with default options because of the AERLIFT step that needs to be performed.

First, as mentioned in section 8.3, beta low-wind options were used in both AERMET (the adjusted u* option: METHOD STABLEBL ADJ_U*) and LOWWIND2 AERMOD option. As also mentioned in 8.3, the AERMOD version 14134 was enhanced to allow users, under the keyword LOW_WIND, to not only define the minimum sigma-v value, but to specify the minimum value for both stable and unstable conditions. Testing has shown that minimum values of 0.4 m/s for unstable and 0.6 m/s best approached observations at both the flat and elevated terrain monitors. The default values for the minimum wind speed (0.2828 m/s) and the meander fraction (0.95) were retained. The inputs were passed in as follows in the control card:

```
CO LOW_WIND  0.4  0.2828  0.95  0.6
```

Furthermore, this modified version of AERMOD (referred to here as “EASTMOD”) also included a customized debugging output option, DISTANCE-DEBUG, that extracts several key hourly plume parameters (including the final plume height, the wind direction and speed at final plume height) for use in the subsequent plume-merging post-processor, AERLIFT. After the DEBUGOPT keyword the DISTAN option (followed by the user supplied output file name) activates this debugging option:

```
CO DEBUGOPT DISTAN MV-Case1-MOD.dbg
```

EASTMOD needs to be run with hourly emissions (via the HOUREMIS keyword). The hourly emission file must also include hourly stack temperature and exit velocity. Finally, as noted in section 8.6, to determine the plume merging solely on the meteorology, EASTMOD is run on flat terrain with a 10km ring of 360 receptors set 1 degree apart.

The main output from this initial EASTMOD run is the DISTANCE-DEBUG output file. AERLIFT uses the hourly, source-specific plume data from the DISTANCE-DEBUG file in its plume merging calculations. Figure 8-2 shows a sample DISTANCE-DEBUG file, with the parameters used by AERLIFT highlighted. AERLIFT also requires the hourly ambient temperature (via the AERMET surface file) as well as the hourly stack temperatures and exit velocities (in the hourly emission file). AERLIFT initially calculates the alignment angle of the stacks that have been noted as being aligned. It should be noted that the current version of AERLIFT can only process one set of aligned sources at a time. Both the 253 and 83 powerhouses contain inline stacks (see Figure 7-3). Hence, first the 253 powerhouse sources and then the 83 powerhouse sources are processed.

Once the alignment angle for the sources is calculated, then AERLIFT proceeds through the hourly data by first assessing if the wind direction at plume height is conducive to plume merging. The angle between the wind direction and the alignment angle (from 0-90°) governs if, and by how much, buoyancy enhancement from plume-merging occurs. As mentioned in Section 8.5, S’ (eqn. 1) provides a measure of how much enhancement is allowed. Based on the Anfossi study, AERLIFT was run with S’ thresholds of 5 and 10, such that maximum possible enhancement could occur for S’ values less than 5, scaled between 5 and 10 and restricted for values over 10. If for a specific hour buoyancy enhancement is allowed, then the enhancement factor (eqn. 4) is calculated (capped by the number of aligned sources emitting at that hour). The enhancement is then applied to the hourly stack temperature and exit velocity. AERLIFT then produces a new hourly emission file with the enhanced hourly stack temperatures and exit velocities. For debugging purposes, AERLIFT produces a FluxInfo.txt file that contains the hourly intermediary variables used in assessing the enhanced buoyancy calculations.

The “AERLIFTed” hourly emission file is then used in a second and final run of Enhanced AERMOD using the same meteorology and modeling options as the initial Enhanced AERMOD run. Other key differences are that this second run is performed on the non-attainment receptors (see section 7.1) and includes the hourly seasonal ambient background (see Figure 8-3).

Figure 8-2: Example Hourly Data from DISTANCE-DEBUG

```
    OBSERVED MET CONDITIONS FOR:   USTAR   WSTAR  OBULEN  URB_OBULEN  ZIMECH  ZICONV   ZI_URB     SFCZ0   THSTAR
    YYMMDDHH: 12040102             (m/s)   (m/s)  (m)     (m)          (m)     (m)      (m)        (m)     (K)
                                    0.13   -9.00   12.90        N.A.  103.00 -999.00    N.A.     0.4280    0.090
   ------------------------------------------------------------------------------------------------------------

 POINT SOURCES:
    SOURCE        RCPT   FINAL  DIST.  WDIR  Effect. <------ DISTANCE -----> MEAND.  PART.   EFFECT. EFFECT.   HOURLY
POT.
     ID           NO.    PLUME  FINAL  FINAL WSPD    3600*      TO     PLUME FRAC.  PEN.    SIGMA_V SIGMA_W   CONC.       AERVAL COHERENT   PANCAKE  GAMFACT
PRMVAL      TEMP.
                         HT.    PL.HT  HT.           ueff       RECEPT TYPE         FRAC.
GRAD.
                         (m)    (m)    (deg)  (m/s)  (m/s)      (m)                         (m/s)   (m/s)     (µg/m3)     (µg/m3)   (µg/m3)     (µg/m3)
(µg/m3)  (K/m)
-----------------------------------------------------------------------------------------------------------------------------------------------------------------
--------------
 P MERGE001        329  153.1   269.4  273.   2.669   9610.1     3242.0 GAU   0.025   0.000   0.200   0.052     35.017      0.000      0.000      0.000  PLUME OUT
OF WAKE  0.01637
   MERGEN01    <--- Source is not emitting during this hour
 P POINT002       1130   31.5   172.3  273.   1.347   4848.7 <  9157.9 GAU   0.090   0.000   0.200   0.074      2.209      2.209      2.422      0.066  PLUME OUT
OF WAKE  0.01637
 P POINT003        329   14.4   158.4  273.   1.347   4848.7     3202.3 GAU   0.073   0.000   0.200   0.074     13.187     13.019     14.021      0.330   1.000
13.187  0.01278
 P POINT004       1099   30.6   172.3  273.   1.347   4848.7 <  8260.8 GAU   0.085   0.000   0.200   0.074      2.880      2.880      3.141      0.055   0.000
6.682  0.01278
 P POINT005        325   16.2   158.4  273.   1.347   4848.7     2779.5 GAU   0.070   0.000   0.200   0.074     15.001     15.001     16.095      0.397   0.000
39.017  0.01278
 P POINT006        332   14.6   158.4  273.   1.347   4848.7     3637.3 GAU   0.077   0.000   0.200   0.074     14.365     14.365     15.528      0.358   0.000
24.576  0.01278
 P POINT007        333   15.6   158.4  273.   1.347   4848.7     3690.4 GAU   0.077   0.000   0.200   0.074     14.284     14.284     15.448      0.354   0.000
23.986  0.00781
```

Figure 8-3: Seasonal by Hour of Day AERMOD Input

```
** Seasonal Values **
** NOTE: First row of seasonal values below is for DJF
**           HOUR:   00    01    02    03    04    05    06    07    08    09    10    11    12    13    14    15    16    17    18    19    20    21
22    23
   BACKGRND SEASHR  1.31  0.79  0.26  0.92  1.57  3.14  1.31  1.57  1.05  2.10  1.57  5.50  2.88  2.62 14.93 10.74  2.36  8.65  3.93  7.60  1.31  1.57
1.31  1.05
   BACKGRND SEASHR  1.05  1.83  0.79  1.05  1.31  0.26  0.52  0.52  2.10  0.79  0.79 10.48  4.45 18.08  4.98  3.14  6.55  2.10  2.62  2.10  1.57  1.31
1.57  2.10
   BACKGRND SEASHR  1.05  0.26  0.26  0.26  0.26  1.31  0.26  0.26  1.05  1.57  4.19  2.88  7.07  6.29  3.67  3.67  3.93  2.36  3.14  2.62  1.57  1.57
1.05  0.26
   BACKGRND SEASHR  1.57  0.79  0.52  0.52  0.52  0.52  0.79  1.31  0.52  1.31  3.41  5.50  7.86 13.89 16.77 10.22  9.17  8.65  5.50  2.36  2.36  2.36
1.31  1.57

   BACKUNIT UG/M3
```

9.0 EASTMOD Results

EASTMOD, which includes Enhanced AERMOD and AERLIFT, was run using the on-site meteorological data processed with the adjusted u_* low wind speed option in AERMET and the LOWWIND modeling option with the split minimum sigma-v explained in Section 8.8. The hourly seasonal ambient background value was included in these model runs. For comparison to observed monitor data, three separate AERMOD runs were performed on a single receptor situated and processed at each the three monitors (Figure 3-1). Furthermore, to better estimate the actual impacts from aligned sources (i.e. the sources at the 83 and 253 powerhouses), hourly emission data were processed through AERLIFT to credit a buoyancy enhancement associated with aligned sources. As with the default AERMOD runs, the EASTMOD and observation period were coincidental, starting from April, 2012 through March, 2013.

The observed and predicted (both default AERMOD and EASTMOD) design concentrations for 1-hour SO_2 are tabulated in Table 9-1. Figure 9-1 plots these results, but also includes the model-to-monitor ratios for each site. As noted in section 5.2, an ideal unbiased model would produce values between 0.9 to 1.1. For the default case (in red), the values range between 1.8 to 2.7 over-prediction. However, for EASTMOD (in green) these values range from 1.0 to 1.2 (the highest for Skyland Drive). From comparison of these pairs of design values, EASTMOD produces much more realistic predictions compared against those of the default AERMOD. Examining the year-long time series of the daily maxima for each monitor, (Figures 9-2, a-c), we note that the EASTMOD approach (in red) produces a sequence of ground concentrations that is both less sharply peaked than the default AERMOD output (Figure 7-5, a-c) and trends better against the observed values (in blue).

The Q-Q plots (Figures 9-3, a-c) for each monitor includes both the default AERMOD and EASTMOD results. For the flat terrain monitors (Meadowview and Ross N. Robinson), EASTMOD (in green) approaches the 1:1 correlation diagonal for not only the design concentration (i.e., the H4H), but down through the lower ranks compared to the default AERMOD (in red). Even though at the elevated terrain Skyland Drive monitor, EASTMOD over-predicts the design concentration, the overall performance of EASTMOD is a marked improvement over that of the default AERMOD results.

For the flat terrain monitors, the top 10 observations occur during the daytime hours with relatively low wind speeds and convective mixing heights of at least 400 m. The predicted top 10 observations also occur during the daytime in low wind conditions, but with convective mixing heights generally below 200 m. For Skyland Drive, the top 10 observations were mostly during daytime hours, with 2 nighttime hours also included, in low to moderate wind speeds. The predicted top 10 values, had a mixture of daytime and nighttime hours (more night than day) and a mix of low and moderate wind speeds.

Table 9-1: Comparison of 1-hour SO_2 Design Concentrations, Observed vs. Predicted (for Default AERMOD and Site-specific EASTMOD)

Site	H4H Concentrations (µg/m³)		
		Predicted	
	Observed	Default	EASTMOD
Meadowview	359.50	730.50	363.20
Ross N. Robinson	428.10	776.00	415.70
Skyland Dr.	406.60	1102.80	495.20

April, 2012 - March, 2013

Figure 9-1: Comparison of Observed vs. Predicted 1-hour SO_2 Design Concentration

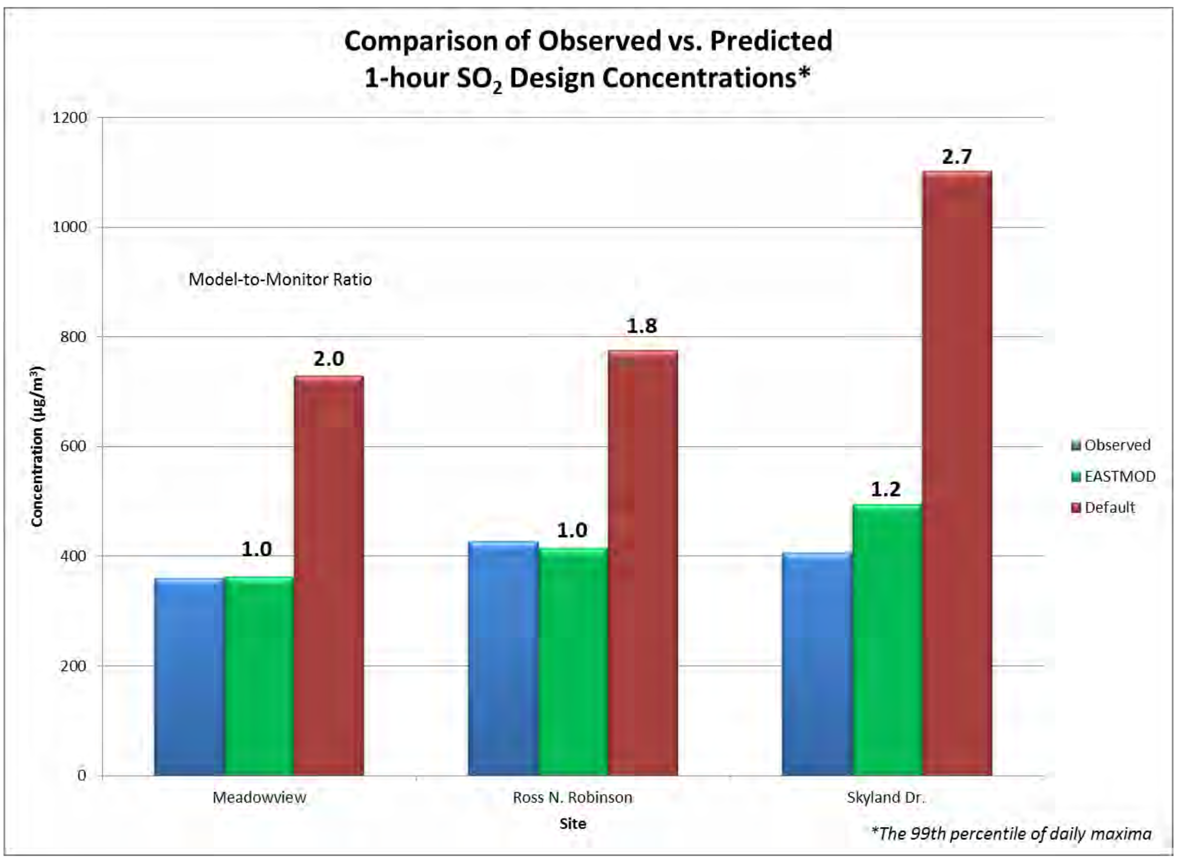


Figure 9-2 (a-c): Time Series of Daily Maxima of Observed (Blue) vs. Predicted (Red) for EASTMOD, at (a) Meadowview, (b) Ross N. Robinson, and (c) Skyland Drive

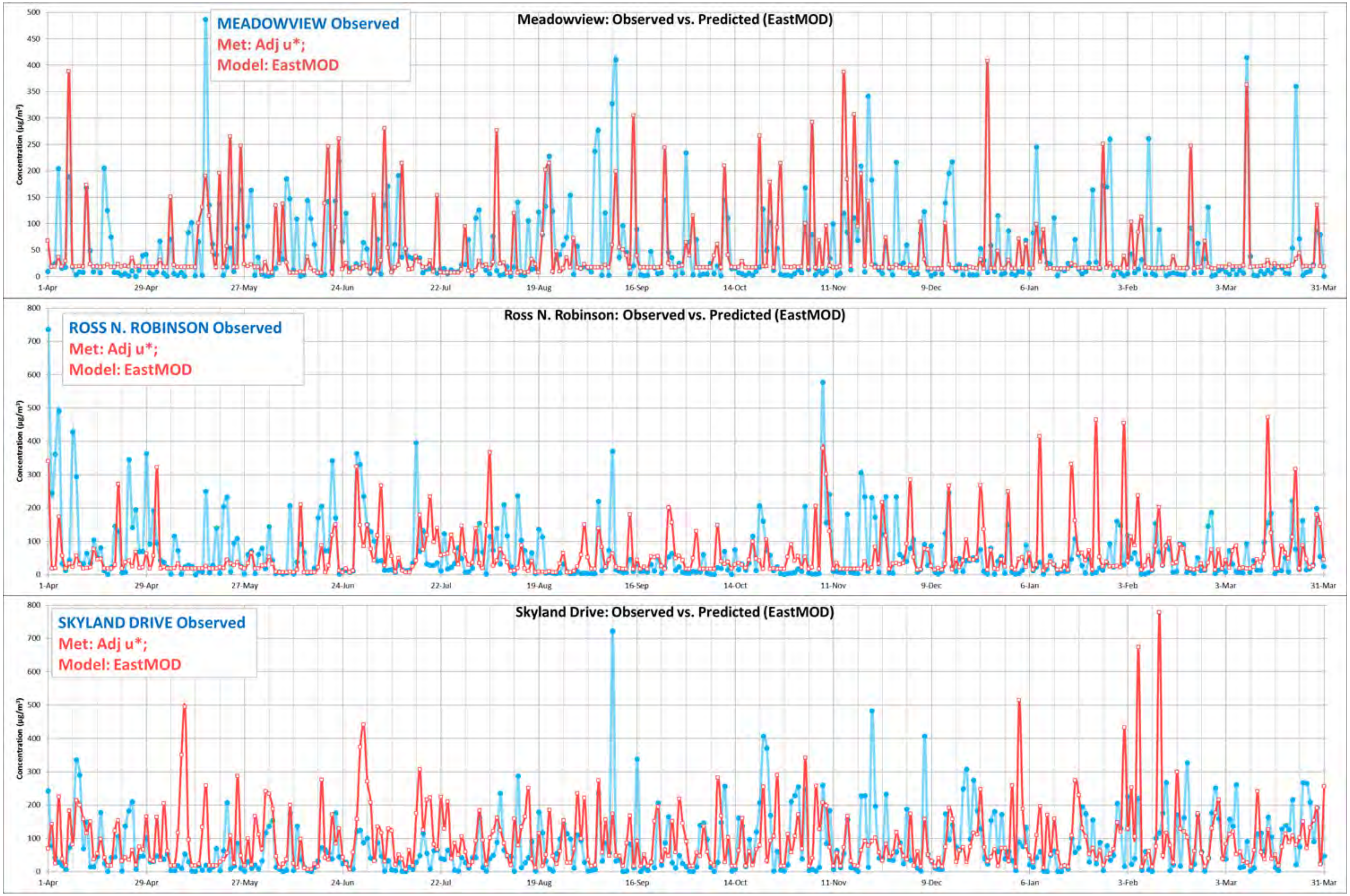
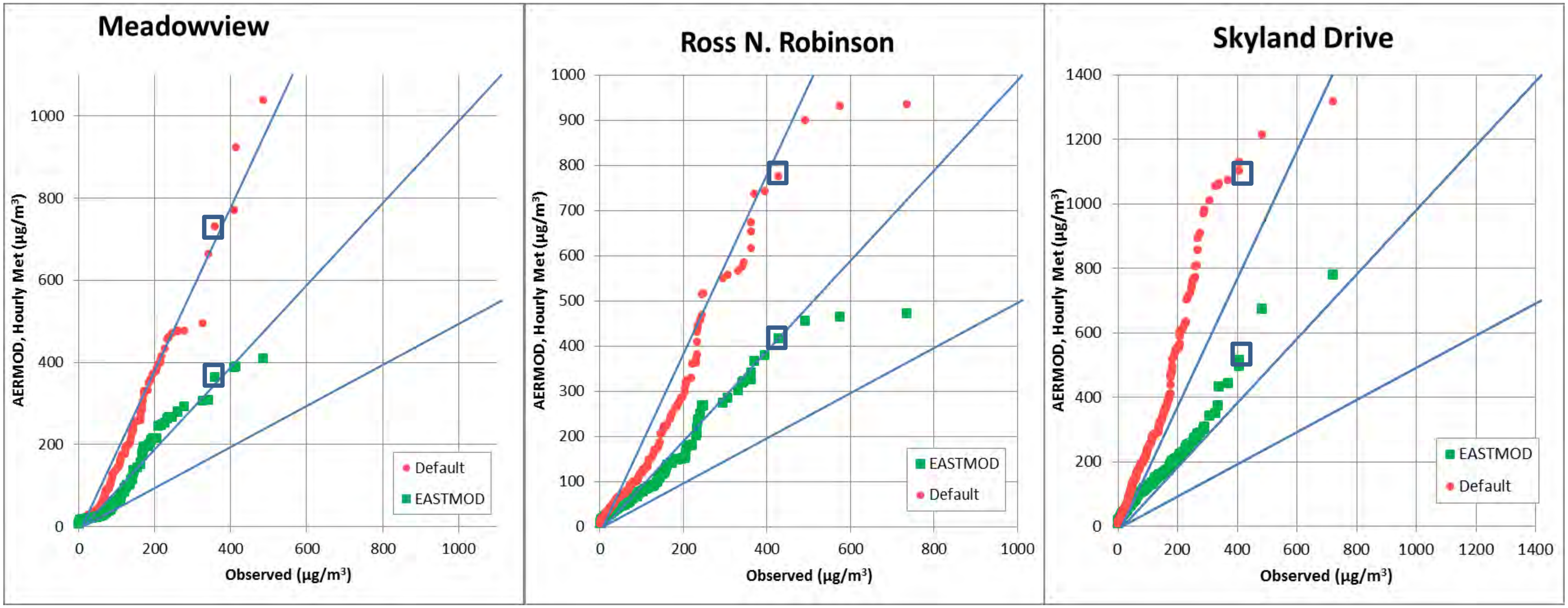


Figure 9-3 (a-c): Q-Q Plots for Observed vs. Predicted



(a) (b) (c)

Notes:

[1]The upper diagonal shows the two-fold model over-prediction and the lower diagonal, the two-fold under-prediction. The central diagonal is the 1:1 correlation line.

[2] The predicted model concentrations include the seasonal by hour-of-day background value.

[3] The boxed values represent the design concentrations (i.e. the High-4th-High)

10.0 Recommendations for Eastman Site-Specific Dispersion Model

The comparison of the performance of AERMOD (default) and EASTMOD clearly indicates that EASTMOD has better performance for this site. Furthermore, the evaluation results indicate an unbiased or over-predicting estimate of air quality concentrations at each monitoring site for EASTMOD. Therefore, use of EASTMOD is expected to be protective of air quality in the Kingsport area.

The formulation of EASTMOD is based upon the EPA-approved AERMOD model, but with scientifically justifiable enhancements, including:

- Improvements in the u_* formulation in the AERMOD meteorological pre-processor;
- Use of a minimum sigma-v averaging 0.5 m/s in AERMOD, which is consistent with findings from other investigators and usage in other models such as SCICHEM;
- Accounting for partial merging of plumes from nearby stacks as computed on an hourly basis using algorithms reported in peer-reviewed technical publications.

Based upon these findings, Eastman and AECOM are providing TDEC and EPA with this documentation and all associated files for the modeling and the site-specific database that are required to completely replicate the model evaluation results. Model documentation for AERLIFT is also provided, as well as for the implementation of the "split" minimum sigma-v in AERMOD. All other aspects of the modeling are those used in normal AERMOD modeling applications.

Attachment F

EPA Region 4 Approval of the use of Low Wind Options for AERMOD version 14134

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION 4
ATLANTA FEDERAL CENTER
61 FORSYTH STREET
ATLANTA, GEORGIA 30303-8960

JUN 0 1 2015

Mr. Barry R. Stephens
Director
Division of Air Pollution Control
Tennessee Department of Environment and Conservation
William R. Snodgrass Tennessee Tower
312 Rosa L. Parks Avenue, 15 Floor
Nashville, Tennessee 37243

RE: Approval of Alternative Model Request
Modeling of Sulfur Dioxide Emissions from Eastman Chemical Company
Sullivan County, Tennessee, 2010 Sulfur Dioxide National Ambient Air Quality Standards (NAAQS) Nonattainment Area

Dear Mr. Stephens:

This letter provides our approval of an alternative model for the attainment demonstration required pursuant to Section 172(c) of the Clean Air Act (CAA), for the Nonattainment Area State Implementation Plan (SIP) for the Sullivan County, Tennessee 2010 1-hour sulfur dioxide (SO_2) Nonattainment Area. The attainment demonstration must contain an air quality modeling analysis which demonstrates that the emission limits in the plan will provide for timely attainment of the standard. The U. S. Environmental Protection Agency's guidance memorandum titled: "Guidance for 1-Hour SO_2 Nonattainment Area SIP Submissions," dated April 23, 2014, indicates that the American Meteorological Society/Environmental Protection Agency Regulatory Model (AERMOD) is the recommended model for SO_2 attainment demonstration modeling analyses. However, the guidance memo also provides flexibility for consideration for use of alternative models on a case-by-case basis when an adequate demonstration is made that the alternative model performs better than AERMOD for a particular application. An adequate demonstration should meet the criteria provided in Section 3.2.2(d) of the EPA's Guideline on Air Quality Models contained in 40 CFR Part 51, Appendix W.

The Eastman Chemical Company has proposed to use an alternative modeling system, which they have called "EASTMOD," to model the SO_2 emissions from their facility located in the Sullivan County SO_2 Nonattainment Area. Based upon a review of all of the information that has been provided by Eastman since the original proposal in 2014, the EPA is approving portions of the proposed changes to the AERMOD Modeling System that are incorporated into the EASTMOD proposal and not approving other portions of the proposal. We have determined that the following modifications to the regulatory AERMOD modeling system are acceptable for modeling Eastman's SO_2 emissions: use of the beta ADJ_U* option in the meteorological preprocessor, AERMET, and use of the LOWWIND2 beta option in AERMOD (with a 0.4 m/s minimum sigma-v value). We have determined that Eastman's proposal to modify the LOWWIND2 beta option to allow use of split minimum sigma-v values for stable and unstable atmospheric conditions is not acceptable.

The EPA has performed considerable testing of both the beta ADJ_U* option in AERMET and the LOWWIND2 beta option in AERMOD using multiple tracer-studies[1]. Since Eastman has shown that the combination of these beta options has improved model performance for their site-specific case, the EPA believes that these alternative model options are appropriate for Tennessee's SO_2 attainment demonstration SIP modeling. As has been stated in previous technical review comments[2], the EPA continues to have concerns about Eastman's proposal to use split minimum sigma-v values for unstable (0.4 m/s) and stable (0.6 m/s) atmospheric conditions, due in part to the fact that the AERMOD model formulation incorporates a horizontal plume meander component that effectively increases lateral plume spread, especially under low wind stable conditions. As a result of these concerns, the EPA does not believe that the additional information provided by Eastman on March 3, 2015, justifies use of this proposed change to the model.

Based upon the site-specific model performance information provided by Eastman[3], it appears that use of the LOWWIND2 beta option with a single minimum sigma-v value of 0.4 m/s significantly improves model performance for the Ross N. Robinson, Meadowview, Skyland Drive and B-267 monitors when compared to the regulatory default version of AERMOD. We are approving a minimum sigma-v value of 0.4 m/s (versus the current default value of 0.3 m/s associated with the beta LOWWIND2 option) for Eastman specific case due to the complex dispersion environment associated with very low wind speeds and nearby complex terrain. These influences are likely to result in significant vertical wind shear that could contribute to increased lateral plume dispersion.

As indicated in our Technical Review Comments dated September 5, 2014, we have determined that the proposed AERLIFT component of EASTMOD is a source characterization procedure and is not an integral part of the AERMOD Modeling System. Therefore, it is not subject to the Appendix W, Section 3.2.2 alternative model evaluation criteria. We have considered the AERLIFT procedure separately from the modifications proposed to be made to the actual AERMOD Modeling System. In order to fully address the modeling procedures being proposed by Eastman, we are also providing our decisions regarding application of the AERLIFT procedure in this letter. Based upon the entirety of information provided by Eastman regarding AERLIFT, the EPA believes that the AERLIFT procedure is acceptable for use in modeling the five closely-spaced stacks at the B-253 powerhouse, but is not acceptable for the two B-83 stacks.

The additional information provided by Eastman in its March 3, 2015, submittal[3] clearly indicates that use of AERLIFT for the five closely spaced B-253 stacks improves model performance at the Ross N. Robinson, Skyland Drive and Meadowview monitor locations and shows a small improvement for the B-267 monitor location when compared to the no-AERLIFT cases. The studies in the references cited by both the EPA and Eastman in previous correspondence provide supporting information for use of AERLIFT for the five closely-spaced (approx. 15 meters apart) B-253 stacks. Conversely, the use of AERLIFT for the two B-83 stacks that are relatively far apart (approx. 50 meter or 11 stack diameters apart) results in very little change to the model performance at the Ross N. Robinson, Skyland Drive, Meadowview and B-267 monitor locations when compared to the no-AERLIFT cases. As has been pointed out in previous EPA comments[2], the literature appears to be consistent regarding the lack of any

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[1] EPA Webinar dated August 12, 2014 (http://www.epa.gov/ttn/scram/webinar/AERMOD_13350_Update/AERMOD_System_Update_Webinar_01-14-2014_FINAL.pdf)

[2] Email from Rick Gillam (EPA) to Haidar Al-Rawli (TDEC) on November 16, 2015, email from Rick Gillam (EPA) to Stephen Gossett (Eastman) dated February 4, 2015, and email from Scott Davis (EPA) to Barry Stephens (TDEC) on April 13, 2015.

[3] Eastman's Responses to Comments dated October 8, 2014, January 20, 2015, and March 3, 2015.

plume rise enhancement for two stacks spaced far apart like the B-83 stacks. The lack of performance improvement with AERLIFT for the B-83 stacks is consistent with the studies which question plume rise enhancement for two far apart stacks. Therefore, the EPA does not believe it is appropriate to approve the use of AERLIFT for the B-83 stacks. The EPA also notes that the additional information provided by Eastman indicates that the importance of the AERLIFT procedure will be greatly reduced for the future attainment year modeling case, in which the B-253 SO_2 emissions will be mostly eliminated by the fuel switch from coal to natural gas for the B-253 boilers.

In summary, we approve the following modifications to the EPA's regulatory AERMOD modeling system (version 14134) for modeling of SO_2 emissions from the Eastman facility for this site-specific SO_2 attainment demonstration modeling application: use of the beta ADJ_U* option in the meteorological preprocessor, AERMET, and use of the LOWWIND2 beta option in AERMOD (with a 0.4 m/s minimum sigma-v value). This approval is being made pursuant to Section 3.2.2(d) of 40 CFR Part 51, Appendix W, and is only applicable for this specific modeling application. Use of these modifications for other applications of the EPA's regulatory AERMOD modeling system are subject to review and approval on a case-by-case basis. Also, please note that our approval of the use of these alternative model options does not represent any determination or disposition on the actual attainment demonstration modeling that will be used for the Sullivan County SO_2 Nonattainment Area SIP nor does it make any final approvability determinations concerning other components of the attainment demonstration SIP submission. If you have any questions regarding the contents of this letter, please contact Rick Gillam at (404) 562-9049.

Sincerely,

Carol L. Kemker for

Beverly H. Banister
Director
Air, Pesticides and Toxics Management Division

Attachment G

EPA Region 10 Approval of the use of the ADJ_U* Option as an Alternative Model

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION 10
1200 Sixth Avenue, Suite 900
Seattle, WA 98101-3140

OFFICE OF
ENVIRONMENTAL ASSESSMENT

20 October 2015

MEMORANDUM

Subject: Surface Friction Velocity (u.) Non-Default/Beta Option in AERMET Version 15181; Alternative Refined Model Demonstration

From: Herman Wong
Region 10 Modeling Contact/Regional Atmospheric Scientist

To: Alan Schuler
Alaska Department of Environmental Conservation, Engineer, P.E.

This U.S. Environmental Protection Agency (EPA), Region 10 (R10) memorandum serves to notify the State of Alaska, Department of Environmental Conservation (ADEC) and the Model Clearinghouse (C/H) in the EPA Office of Air Quality Planning and Standards (OAQPS) of its decision to approve the use of the surface friction velocity (u.) non-default/beta option (u. option) in Version 15181 of the American Meteorological Society/Environmental Protection Agency Regulatory Improvement Committee (AERMIC) meteorological (AERMET) preprocessor program.[1] The R10 authority for such an approval are found in Sections 3.0.b and 3.2.2.a of Appendix W[2] and in the 1988 Model C/H Operational Plan.[3]

With the *Revision to the Guideline on Air Quality Models: Enhancement to the AERMOD Dispersion Modeling System and Incorporation of Approaches to Address Ozone and Fine Particulate Matter* proposed rulemaking published in 80 FR 45340 on 29 July 2015, ADEC in its 17 September 2015 letter[4] contained in Attachment A, requested R10 approval to allow an applicant to use the u. option in the AERMET preprocessor program and the "BETA" keyword under the CO MODELOPT pathway in the American Meteorological Society/Environmental Protection Agency Regulatory Model (AERMOD) dispersion program under 18 AAC 50.215(c).[5] These two programs along with Version 11.103 of the AERMIC terrain preprocessor (AERMAP)

[1] EPA. 2015. Addendum, User's Guide for the AERMOD Meteorological Preprocessor (AERMET). (EPA-454/B-03-002, November 2004). Office of Air Quality Planning and Standards, Research Triangle Park, NC. June.

[2] Code of Federal Regulations; Title 40 (Protection of Environment.), Part 51, Appendix W, Section 3,

[3] EPA. 1988. Model Clearinghouse: Operation Plan (Revised). Staff Report. Office of Air Quality Planning and Standards, Research Triangle Park, NC. June 7.

[4] Schuler, A. 2015. Request to Use Adjusted u. Option for the Dolin Gold Project. Department of Environmental Conservation, 410 Willoughby Ave, Suite 303, Juneau, AK. September 17.

[5] Alaska Air Quality Control Regulations. Title 18, Environmental Conservation - Air Quality

program[6] will be utilized to estimate the Donlin Gold Limited Liability Company (DGLLC) mine construction and mine operation air pollutant emission impacts in ambient air to determine compliance with National Ambient Air Quality Standards (NAAQS)[7] and Prevention of Significant Deterioration (PSD) air quality increments.[8] The gold mine construction and/or operation compliance demonstrations will be submitted to ADEC as part of a PSD permit application and to the U.S. Army Corps of Engineers (Lead Agency) for inclusion in an Environmental Impact Statement (EIS) under the National Environmental Policy Act (NEPA).[9] The State of Alaska (AK) administrative code stipulates that an EPA preferred model may be substituted for an alternative model provided a demonstration is made pursuant to Section 3 in Appendix W of 40 CFR 51 and is approved by the R10 Regional Administrator.

The following sections describe the proposed project and discuss the bases for the R10 approval.

A. Project Overview

The DGLLC gold mine project will be located in topographic relief on the western slopes of the Kuskokwin Mountains in the Yukon-Kuskokwin region of southwestern Alaska as shown in Figure 1. Elevations range from 500 to 2,100 feet (ft). Ridges are well rounded.

The remote project area has no existing roads, rail access, or other public infrastructure. DGLLC currently accesses the area by air, using a private airstrip that they constructed near the site. To support the major mining and processing operations, DGLLC will construct significant infrastructure that includes a natural gas pipeline, power generation sources, an onsite employee accommodation complex, roads, ports, shipping and barging facilities.

Based on existing design, DGLLC proposes to construct and operate an open-pit gold mine, tailings and waste rock facilities, a process plant with a nominal production rate of 59,000 short tons of ore per day, a 220 megawatt power plant, and various ancillary sources. DGLLC intends to characterize the air emissions, including the fugitive dust emissions from the associated haul and access roads as 80 point, 398 volume, 46 area, and one open pit source for modeling purposes.[10] Point source stack heights range from 2.0 meters (m) for the dust collectors on the Apron Feeders (which are part of the rock crushing system) to 49.0 m for the 12 Wartsila power plant engines. Volume sources include haul road segments and blasting. Haul road segments are the most numerous with a release height of 6.97 m. Blasting operations will have a release height of 75.0 m. Areas sources include tailing storage facilities and access roads. Figure 2 shows an overhead view of the emission source layout.

Surface observations from the onsite American Ridge meteorological monitoring station, upper air data from the McGrath National Weather Service (NWS) station, and cloud cover data

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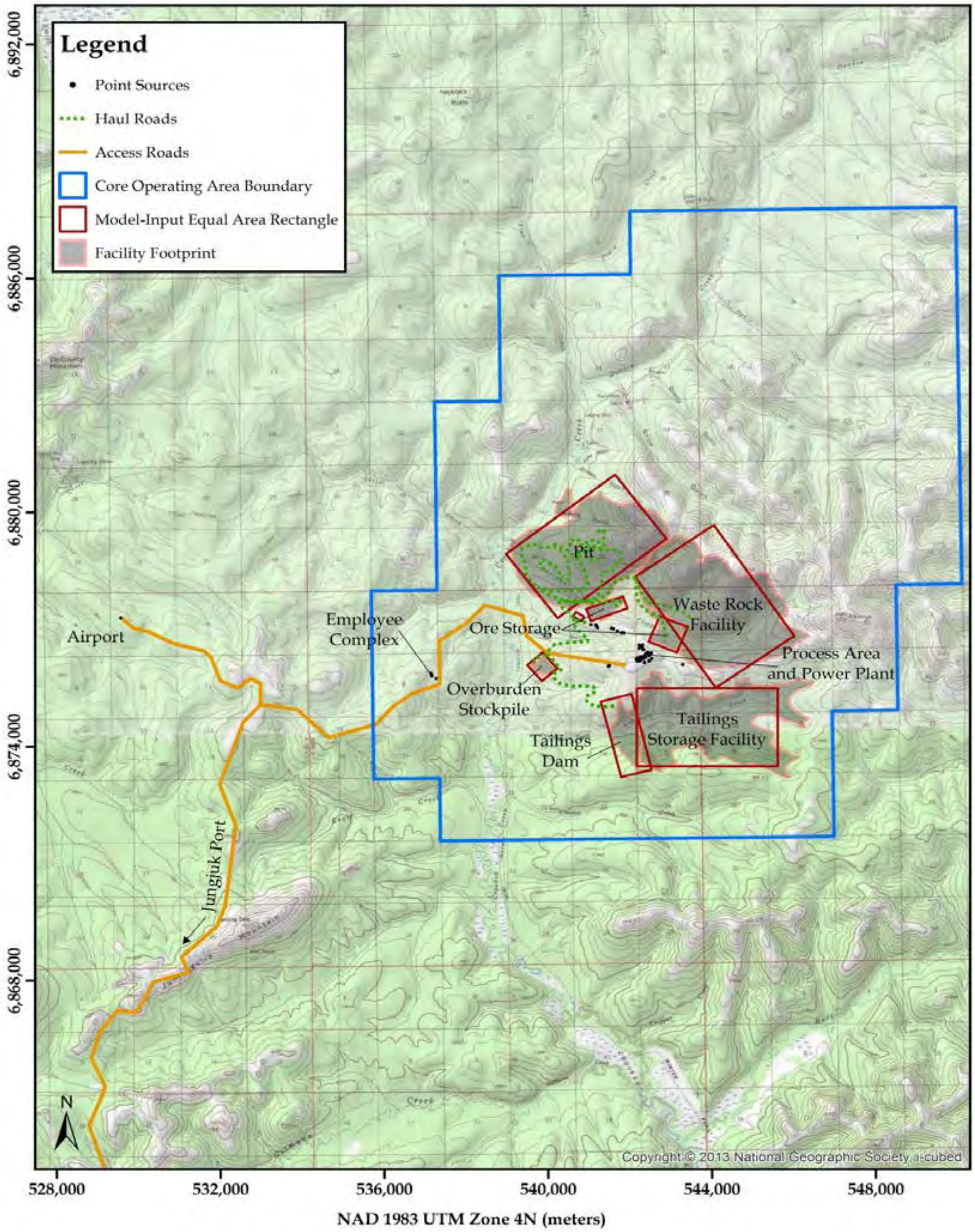
[6] EPA. 2011. Addendum, User's Guide for the AERMOD Terrain Preprocessor (AERMAP) (EPA-454/B-03-003, October 2004). Office of Air Quality Planning and Standards, Research Triangle Park, NC. March.
[7] Code of Federal Regulations; Title 40 (Protection of Environment), Part 50 – National Primary and Secondary Ambient Air Quality Standards.
[8] Code of Federal Regulations; Title 40 (Protection of Environment), Part 52 – Approval and Promulgation of Implementation Plans.
[9] 42 U.S.C. 4321
[10] Air Sciences. 2015. Class II PSD Increment and AAQS Compliance Modeling Protocol, Donlin Gold Project, Alaska. Project No. 281-15-2. Prepared for DGLLC. July.

Figure 1. Project Location.

Source: Air Sciences. 2015. Class II PSD Increment and AAQS Compliance Modeling Protocol, Donlin Gold Project, Alaska. Project No. 281-15-2. Prepared for DGLLC. July.

Figure 2. Proposed Emission Source Layout.



Source: Air Sciences. 2015. Class II PSD Increment and AAQS Compliance Modeling Protocol, Donlin Gold Project, Alaska. Project No. 281-15-2. Prepared for DGLLC. July.

from Sleetmute NWS station will be read by AERMET to build and output a surface file and a profile file for input into the AERMOD dispersion program to estimate air pollutant concentration impacts. The hourly surface observations were reviewed by ADEC and were found acceptable.[11] In lieu of the Bulk Richardson option, DGLLC will use Sleetmute cloud cover data which was determined by ADEC to be representative.[12] [13] The five year period of record for the data ranges from 1 July 2005 to 30 June 2010. Figure 3 shows the locations of the meteorological monitoring stations.

B. Regulatory Compliance and Demonstration for Use of a Non-Default/Beta Option in a Preferred Model

An alternative option in a preferred model may be used if it is found to be more appropriate than the preferred model. Section 3.2.2.b in Appendix W states that "There are three conditions under which such a model may normally be approved for use: (1) If a demonstration can be made that the model produces concentration estimates equivalent to the estimates obtained using a preferred model; (2) if a statistical performance evaluation has been conducted using measured air quality data and the result of the evaluation indicate the alternative model performs better for the given application than a comparable model in Appendix A; or (3) if the preferred model is less appropriate for the specific application, or there is no preferred model." R10 authority to accept and approve the use of an alternative option in a preferred model is given in Section 3.0.b and 3.2.2.a of Appendix W and in the 1988 revised Model Clearinghouse Plan.

In the following three subsections, four EPA Model Change Bulletins (MCB) related to the Qian and Venkatram u_* equations[14] coded into AERMET are summarized, a DGLLC demonstration consistent with Appendix W, Section 3.3.2.b(2)[15] [16] to use the u_* option in lieu of the current AERMET hard-coded u_* Default Method is presented, and a R10 description of the other meteorological variables affected by the u_* option is provided. The keyword "BETA" will be specified in MODELOPT since u_* is a non-default option in the AERMOD dispersion program per the June 2015 Addendum to the user's guide.

B.1 EPA Model Change Bulletin

In an effort to address AERMOD's propensity to overestimate concentration estimates during low wind speed stable conditions, EPA updated the AERMET source code with the Qian

[11] Schuler, A. 2015. Approval of the July 2015 Prevention of Significant Deterioration (PSD) Modeling Protocol for the Donlin Gold Project. Department of Environmental Conservation, 410 Willoughby Ave, Suite 303, Juneau, AK. September 28.

[12] Schuler, A. 2013. Email to Robert Enos, DGLLC *Donlin May Use Sleetmute Cloud Cover Data*. Department of Environmental Conservation, 410 Willoughby Ave, Suite 303, Juneau, AK. October 1.

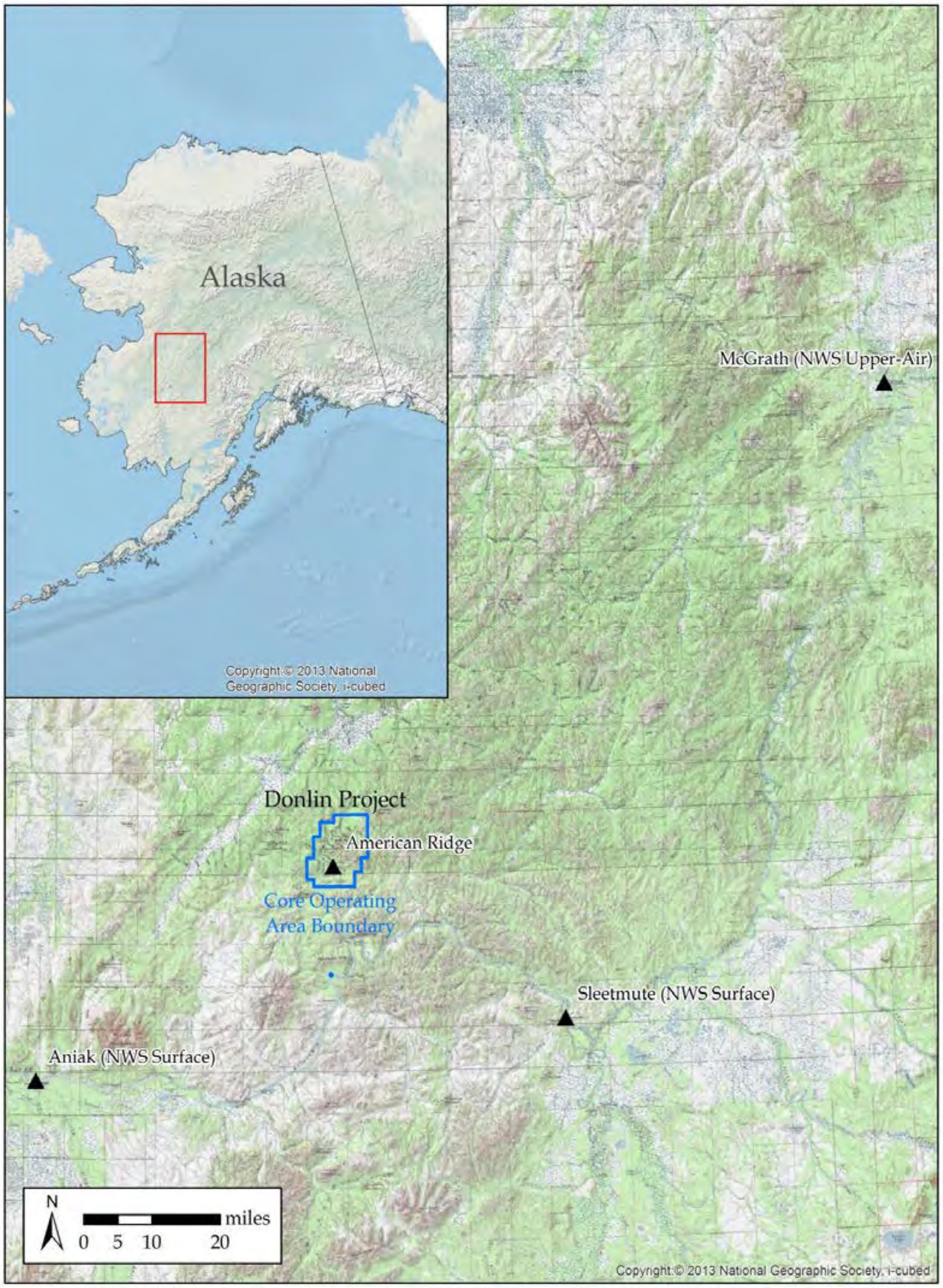
[13] Renovatio, J 2015. Email to Mike Rieser, DGLLC *FW: Cloud cover for Donlin*. Department of Environmental Conservation, 410 Willoughby Ave, Suite 303, Juneau, AK. February 3.

[14] Qian, Wenjun and Akula Venkatram. 2011. Performance of Steady-State Dispersion Models Under Low Sped Conditions. Boundary Layer Meteorology, 138:475-491.

[15] DGLLC. 2015. Additional Information Regarding DGLLC's Adj_u_* Approval Request to Alan Schuler, Alaska Department of Environmental Conservation. Donlin Gold, 4720 Business Park, Suite G-25, Anchorage, AK. August 25.

[16] DGLLC. 2015. Responses to EPA R10 Comments on DGLLC's Adj_u_* Approval Request to Alan Schuler, Alaska Department of Environmental Conservation. Donlin Gold, 4720 Business Park, Suite G-25, Anchorage, AK. September 2.

Figure 3. Meteorological Monitoring Station Location Map.



Source: Air Sciences. 2015. Class II PSD Increment and AAQS Compliance Modeling Protocol, Donlin Gold Project, Alaska. Project No. 281-15-2. Prepared for DGLLC. July.

and Venkatram equations for u_*. EPA also coded three non-default low wind options into AERMOD, any of which may be selected with or without the u_* option. However, DGLLC is not seeking R10 approval to use any of the non-default/beta low wind speed options in AERMOD.

Starting with AERMOD Version 12345, the Model C/H added the u_* option to address overpredicted concentration estimates associated with low wind speed under stable conditions (i.e., Monin-Obukhov [M-O] length > 0). This option was subsequently updated in Versions 13350, 14134 and 15181 with the latter proposed as regulatory default on 29 July 2015. The sequence of changes to AERMET are as follows:

1. Version 12345 - Model C/H first coded the u_* option into UCALST subroutine.[17]
2. Version 13350 - Model C/H modified the UCALST subroutine per AECOM recommendation to correct the scaling temperature (θ_*) in the u_* option.[18] [19] In addition, Model C/H modified the BULKRI subroutine to incorporate a Bulk Richardson (BULKRN) option for u_* based on Luhar and Raynor. [20]
3. Version 14134 - Model C/H modified BULKRI subroutine to include θ_* adjustment for low solar elevation angle and for the u_* option associated with the BULKRN option.[21]
4. Version 15181 - Modified subroutines UCALST and MPPBL to use a constant θ_* equal to 0.8, full inclusion of the displacement height, and a modified formulation of the M-O Length for u_* option based on Qian and Venkatram.[22]

With Version 15181, the Model C/H believed that there was sufficient analyses and evaluations completed internally and externally to propose the inclusion of the u_* option into Appendix W and make it a regulatory default option in AERMET.

B.2 DGLLC Demonstration to Use Adjusted u_* Option

The following paragraphs have been extracted in part from DGLLC letters dated 25 August 2015 and 2 September 2015 which are contained in Attachment B and Attachment C, respectively. DGLLC had requested R10 approval through ADEC to employ the u_* option in AERMET based on the analyses and evaluation used in the EPA Appendix W proposal.

During the January 2014 webinar, EPA presented preliminary model performance evaluation results from a low wind-speed study at Oak Ridge, TN in complex terrain. The webinar also provided results from an evaluation of the Cordero

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[17] EPA. 2012. Model Change Bulletin #3, AERMET (dated 12345). Office of Air Quality Planning and Standards, Research Triangle Park, NC. December 10.

[18] AECOM. 2012. AERMOD Low Speed Evaluation Study by Bob Paine at EPA 10th Modeling Conference. March 13.

[19] EPA. 2013. Model Change Bulletin #4, AERMET (dated 13350). Office of Air Quality Planning and Standards, Research Triangle Park, NC. December 16.

[20] Luhar, A. K. and K. N. Rayner. 2009. Methods to Estimate Surface Fluxes of Momentum and Heat from Routine Weather Observations for Dispersion Application under Stable Stratification. Boundary Layer Meteorology, 132:437-454.

[21] EPA. 2014. Model Change Bulletin #5, AERMET (dated 14134). Office of Air Quality Planning and Standards, Research Triangle Park, NC. May 14.

[22] EPA. 2014. Model Change Bulletin #6, AERMET (dated 15181). Office of Air Quality Planning and Standards, Research Triangle Park, NC. June 30.

Rojo surface coal mine study in Wyoming, examining monitored PM_{10} (particulate matter equal to or less than 10 microns in aerodynamic diameter) concentrations compared to modeled concentrations. A surface coal mine would have emission characteristics similar to those from the DGLLC project. Both studies showed that AERMOD simulations using the u_* option demonstrate significantly improved correlation to field data compared to the Default Method. Additionally in the webinar, EPA presented results from a model evaluation of the Idaho Falls tracer gas study for a low-level, non-buoyant release which also showed that the use of the u_* option improved model performance.

In the June 2015 Addendum to the AERMOD User's Guide, EPA provided model evaluation results using AERMET/AERMOD version 15181 for the Oak Ridge and Idaho Falls tracer studies. Evaluation of the u_* option applied to these studies also showed improved model performance for version 15181 compared to the Default Method. Additionally, EPA performed an evaluation of u_* as applied to a tall stack (145 meters) in complex terrain for the Lovett Power Plant, New York study. Again, the u_* option improved model performance when compared to observations. Updated results from the Cordero Rojo surface coal mine study were not included in the AERMET/AERMOD version 15181 evaluation studies. However, per a presentation at the 2015 Modeling Conference, EPA stated that it expected that the u_* evaluation results for that study "are likely to be similar for v15181". (R10 contacted the Model C/H to confirm that AERMET/AERMOD version 15181 had been run and the results were similar.[23])

For these four studies, model performance improved significantly with the use of the u_* option compared to the Default Method. These studies are relevant to the proposed DGLLC project due to similarities in terrain (complex) and emission characteristics (fugitive sources with low release heights or tall stacks, such as DGLLC's power plant stacks). Table 1 provides a summary of EPA's AERMET/AERMOD version 15181 u_* option evaluation studies in the June 2015 Addendum to the AERMOD User's Guide and the Cordero Rojo surface coal mine study presented in EPA's 2014 webinar.

DGLLC believes that the model evaluations performed by the EPA - presented in the 2014 webinar, and updated for AERMET/AERMOD version 15181 in the Users' Guide Addendum—sufficiently address the performance requirements of Sections in 3.2.2.b(2) and 3.2.2(d) for DGLLC's proposed use of the u_* option. Therefore, DGLLC seeks R10 and ADEC approval for application of the u_* option in the AERMOD modeling for the gold mine project under Section 3.2.2.b(2) of Appendix W.

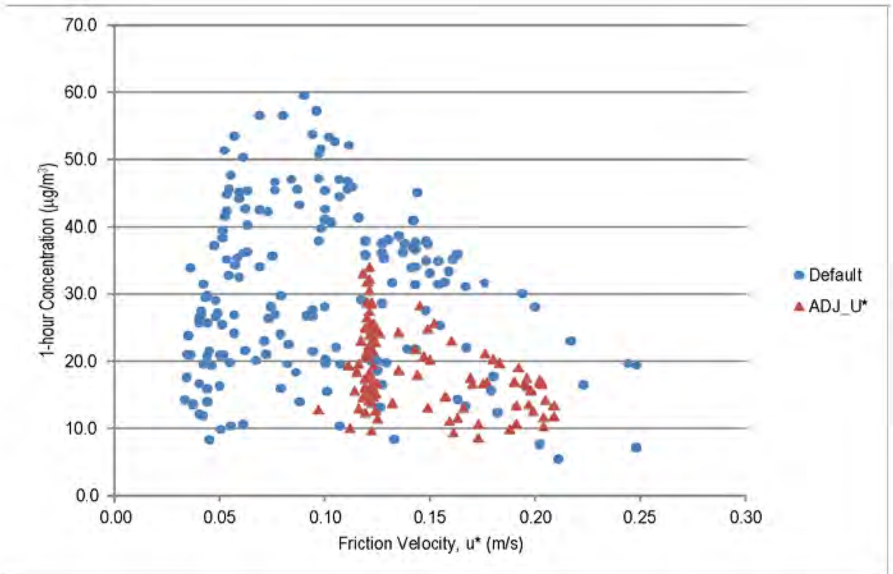
DGLLC provided an AERMOD sensitivity analysis with their u_* option request. They modeled PM_{10} emissions since that would include fugitive dust sources using what they considered to be the worst-case meteorological period. Figure 4 highlights the difference in using the u_* option and the Default Method when predicting hourly concentrations for haul roads. The u_* option values are generally greater than 0.10 meters per second (m/sec) and the hourly predicted concentrations are less than 35 micrograms per cubic meter ($\mu g/m^3$). In the Default Method, u_* are as low as 0.04 m/sec with predicted hourly concentrations as high as 60 $\mu g/m^3$.

[23] Wong, H. 2015. Region 10 telephone conversation with R. Brode, EPA Model Clearinghouse. Office of Environmental Assessment, Seattle, WA. September 30.

Table 1. Summary of EPA's ADJ_U* Evaluations for AERMET/ AERMOD Version 15181

Study Name	Release Type	Terrain / Surroundings	Applicable to Donlin?	Model Performance Without ADJ_U*	Model Performance With ADJ_U*	Overall Conclusions
Oak Ridge	Low-level, non-buoyant release (1 m)	Complex terrain, Rural, Open-area	Yes - Donlin is located in complex terrain and has numerous, low-level fugitive emission sources	Model over-predicts observations by a factor of 2 to 30 (EPA 2015b, Pages F-6 and F-11)	Model agrees with observations within a factor of 1 to 2 (EPA 2015b, Pages F-8 and F-14)	"significant improvement in model performance with the ADJ_U* option in AERMET" (EPA 2015b, Page F-16).
Idaho Falls	Low-level, non-buoyant release (3 m)	Flat/even terrain, Open-area	Yes - Donlin has low-level, non-buoyant fugitive sources, but terrain is different	Model over-predicts observations by a factor of 2 (EPA 2015b, Pages F-6 and F-11)	Model agrees with observations within a factor of 1 to 2 (EPA 2015b, Pages F-25 and F-26)	Generally good model performance at receptors nearest the release. As noted by EPA, "For this type of source, i.e., a non-buoyant, ground-level or low-level source (e.g., fugitive emission), the maximum ambient impacts are likely to occur at the fenceline" (EPA 2015b, Page F-18). Relevant to DGLLC operations/modeling.
Lovett	Tall stack (145 m)	Complex terrain, Rural, Open-area	Yes - Donlin is located in complex terrain and has tall point sources such as the power plant stacks (49 m)	"Past evaluations of AERMOD have shown good performance" (EPA 2015b, Page F-33). The consideration of ADJ_U* reduces the model over-predictions slightly.		Model performance improvement when using ADJ_U* (EPA 2015b, Pages F-33 and F-34).
Cordero Rojo (Wyoming surface coal mine)	Surface mine; majority of emissions from haul roads	Flat/even terrain, Rural, Open-area	Yes - Donlin has low-level, non-buoyant fugitive sources, but terrain is different	EPA evaluated ADJ_U* for AERMOD version 14134, not for version 15181. "Use of the proposed ADJ_U* option in AERMET appears to significantly improve model performance for this study" (EPA 2015d).		Significant improvement in model performance when using ADJ_U*. The results for this study are "based on v14134, but are likely to be similar for v15181" (EPA 2015d).

Figure 4. Haul Road Source Group: u_* Option and u_* Default Method Comparison
(Note: 10-degree sector winds, 0 < M-O < 50 m)



B.3 R10 Analysis of Meteorological Variables Affected by the u_* Option

Most, if not all of the evaluations and analyses have focused on the influence of u_* on AERMOD predicted concentrations. However, no discussion or analysis was presented for heat flux, mechanical mixing height and M-O Length which uses u_* to derive their numerical value. This subsection presents a comparison of these three calculated meteorological variables based on the u_* option and the Default Method.

In the MPPBL subroutine of AERMET, a call is made to UCALST which calculates a u_* value for a specified hour. The calculated u_* then is returned to UCALST to derive heat flux, mechanical mixing height and M-O Length. Tables 2 – 8 presents a numerical comparison of these calculated four meteorological parameters using the u_* option and the Default Method. Figures 5-11 presents the tabulated results graphically. These tabular and graphics summaries were based on the High, Second-High (HSH) predicted concentrations for each of the seven source groups used by DGLLC in their AERMOD sensitivity analysis.

General Observations:

1. The HSH concentrations for all seven source groups occurred during November to February. In northern latitudes, where the project is located, these months are characterized by short days with very low sun angles and very stable conditions. An example is the Power Plant Source Group presented in Table 4 and Figure 7 in which there was 24 hours of M-O > 0.
2. For all seven groups, the u_* option based surface friction velocity, heat flux and mechanical mixing height are greater than those based on the Default Method.

Table 2. Affected Hourly Meteorological Variables With and Without u_* Option for HSH Concentration - All Sources/Groups

YR	MO	DY	JDY	HR	Qian and Venkatram				Default			
					H	u_*	Z_{im}	L	H	u_*	Z_{im}	L
5	12	26	360	9	-6.1	0.120	100	24.2	-2.3	0.055	31	6.1
5	12	26	360	10	-5.6	0.120	100	26.4	-1.9	0.050	27	5.6
5	12	26	360	11	-6.1	0.120	100	23.9	-2.3	0.055	31	6.1
5	12	26	360	12	-23.5	0.234	271	60.1	-9.9	0.114	92	12.7
5	12	26	360	13	-40.7	0.444	709	216.6	-27.0	0.385	574	179.4
5	12	26	360	14	-8.9	0.143	266	27.6	-2.9	0.072	260	11.0
5	12	26	360	15	-24.0	0.259	315	73.5	-11.5	0.185	192	46.8
5	12	26	360	17	-3.1	0.118	97	43.9	-0.7	0.030	12	3.1
5	12	26	360	18	-4.5	0.120	100	32.9	-0.9	0.040	19	6.3
5	12	26	360	19	-5.7	0.120	100	25.7	-1.6	0.051	28	7.4
5	12	26	360	20	-6.5	0.120	100	22.5	-2.6	0.059	34	6.5
5	12	26	360	22	-9.6	0.143	130	26.1	-3.9	0.073	47	8.3
5	12	26	360	23	-24.3	0.241	284	63.8	-10.5	0.117	96	13.1
5	12	26	360	24	-8.6	0.135	125	24.5	-3.6	0.069	43	7.6

Table 3. Affected Hourly Meteorological Variables With and Without u_* Option for HSH Concentration – Process and Auxiliary Sources

					Qian and Venkatram				Default			
YR	MO	DY	JDY	HR	H	u_*	Z_{im}	L	H	u_*	Z_{im}	L
6	1	1	1	1	-5.6	0.121	101	26.5	-1.9	0.050	27	5.5
6	1	1	1	2	-3.9	0.121	101	38.0	-0.9	0.035	16	4.1
6	1	1	1	4	-4.0	0.118	98	34.6	-1.2	0.038	18	3.9
6	1	1	1	6	-5.8	0.121	101	25.9	-2.0	0.051	28	5.8
6	1	1	1	7	-7.3	0.124	105	22.3	-3.1	0.063	38	7.0
6	1	1	1	8	-3.9	0.121	101	38.0	-0.9	0.035	16	3.9
6	1	1	1	9	-14.3	0.176	177	34.1	-5.9	0.088	62	9.7
6	1	1	1	10	-6.4	0.120	101	23.1	-2.5	0.057	33	6.3
6	1	1	1	11	-25.5	0.251	301	69.2	-11.0	0.163	157	32.9
6	1	1	1	12	-23.3	0.231	266	58.6	-9.7	0.113	91	12.5
6	1	1	1	14	-3.8	0.112	90	31.3	-0.9	0.040	19	6.1
6	1	1	1	17	-3.7	0.121	101	40.3	-0.6	0.033	14	4.7
6	1	1	1	18	-4.7	0.121	101	31.5	-1.1	0.042	21	6.0
6	1	1	1	20	-5.9	0.121	101	25.6	-1.6	0.052	29	7.4
6	1	1	1	22	-10.6	0.150	140	27.2	-4.4	0.076	50	8.3
6	1	1	1	24	-5.1	0.121	101	29.3	-1.6	0.045	23	5.0

Table 4. Affected Hourly Meteorological Variables With and Without u_* Option for HSH Concentration – Power Plant Sources

YR	MO	DY	JDY	HR	Qian and Venkatram				Default			
					H	u_*	Z_{im}	L	H	u_*	Z_{im}	L
5	12	7	341	1	-64.0	0.699	1401	538.1	-60.7	0.624	1181	340.6
5	12	7	341	2	-64.0	0.742	1531	605.7	-44.2	0.672	1319	583.0
5	12	7	341	3	-64.0	0.777	1641	664.2	-64.0	0.696	1391	445.9
5	12	7	341	4	-56.9	0.580	1106	370.1	-49.0	0.508	906	226.0
5	12	7	341	5	-56.8	0.578	1057	368.1	-48.9	0.506	864	223.7
5	12	7	341	6	-60.8	0.619	1168	422.1	-31.0	0.561	1007	479.9
5	12	7	341	7	-63.8	0.650	1257	465.3	-32.5	0.590	1085	530.0
5	12	7	341	8	-63.5	0.647	1250	461.1	-32.4	0.587	1079	524.0
5	12	7	341	9	-63.6	0.650	1259	465.3	-43.6	0.583	1067	380.1
5	12	7	341	10	-64.0	0.852	1883	809.0	-42.3	0.773	1629	915.3
5	12	7	341	11	-64.0	0.759	1602	633.1	-37.5	0.690	1387	731.2
5	12	7	341	12	-64.0	0.710	1442	553.9	-50.4	0.639	1231	432.2
5	12	7	341	13	-54.0	0.630	1210	436.4	-53.4	0.554	998	264.9
5	12	7	341	14	-64.0	0.811	1750	724.1	-36.5	0.738	1520	917.4
5	12	7	341	15	-64.0	0.950	2214	1114.7	-43.9	0.862	1915	1214.0
5	12	7	341	16	-64.0	0.894	2038	927.6	-64.0	0.804	1741	676.2
5	12	7	341	17	-64.0	0.777	1668	663.3	-45.2	0.703	1432	638.1
5	12	7	341	18	-64.0	1.073	2658	1602.6	-52.4	0.972	2295	1456.7
5	12	7	341	19	-64.0	1.038	2544	1449.6	-50.7	0.940	2195	1361.7
5	12	7	341	20	-64.0	0.968	2303	1177.3	-47.3	0.878	1986	1187.5
5	12	7	341	21	-64.0	0.968	2287	1177.3	-47.2	0.878	1974	1188.7
5	12	7	341	22	-64.0	1.024	2480	1395.2	-49.9	0.929	2141	1331.8
5	12	7	341	23	-64.0	1.014	2452	1353.4	-49.4	0.919	2116	1305.9
5	12	7	341	24	-64.0	0.837	1890	770.4	-40.9	0.760	1629	892.6

Table 5. Affected Hourly Meteorological Variables With and Without u_* Option for HSH Concentration - Haul Road Sources

YR	MO	DY	JDY	HR	Qian and Venkatram				Default			
					H	u_*	Z_{im}	L	H	u_*	Z_{IM}	L
5	12	26	360	9	-6.1	0.120	100	24.2	-2.3	0.055	31	6.1
5	12	26	360	10	-5.6	0.120	100	26.4	-1.9	0.050	27	5.6
5	12	26	360	11	-6.1	0.120	100	23.9	-2.3	0.055	31	6.1
5	12	26	360	12	-23.5	0.234	271	60.1	-9.9	0.114	92	12.7
5	12	26	360	13	-40.7	0.444	709	216.6	-27.0	0.385	574	179.4
5	12	26	360	14	-8.9	0.143	266	27.6	-2.9	0.072	260	11.0
5	12	26	360	15	-24.0	0.259	315	73.5	-11.5	0.185	192	46.8
5	12	26	360	17	-3.1	0.118	97	43.9	-0.7	0.030	12	3.1
5	12	26	360	18	-4.5	0.120	100	32.9	-0.9	0.040	19	6.3
5	12	26	360	19	-5.7	0.120	100	25.7	-1.6	0.051	28	7.4
5	12	26	360	20	-6.5	0.120	100	22.5	-2.6	0.059	34	6.5
5	12	26	360	22	-9.6	0.143	130	26.1	-3.9	0.073	47	8.3
5	12	26	360	23	-24.3	0.241	284	63.8	-10.5	0.117	96	13.1
5	12	26	360	24	-8.6	0.135	125	24.5	-3.6	0.069	43	7.6

Table 6. Affected Hourly Meteorological Variables With and Without u_* Option for HSH Concentration – Blasting Sources

YR	MO	DY	JDY	HR	Qian and Venkatram				Default			
					H	u_*	Z_{im}	L	H	u_*	Z_{im}	L
6	1	31	31	7	-4.8	0.125	106	34.9	-0.9	0.040	19	5.9
6	1	31	31	8	-3.8	0.121	101	39.4	-1.0	0.033	15	3.2
6	1	31	31	11	-4.2	0.124	105	39.2	-1.0	0.035	16	3.7
6	1	31	31	13	-14.1	0.189	198	41.1	-3.2	0.086	60	16.5
6	1	31	31	14	-6.0	0.126	109	28.9	-1.4	0.059	34	12.2
6	1	31	31	15	-4.0	0.101	77	21.8	-1.2	0.051	28	9.7
6	1	31	31	16	-5.0	0.110	88	22.7	-1.4	0.053	30	9.1
6	1	31	31	17	-29.5	0.307	409	103.8	-6.3	0.113	91	19.1
6	1	31	31	18	-46.3	0.427	669	200.3	-18.4	0.162	157	19.8
6	1	31	31	19	-9.0	0.136	247	23.8	-3.0	0.064	45	7.3
6	1	31	31	20	-7.3	0.125	109	22.7	-2.9	0.061	36	6.5
6	1	31	31	21	-6.2	0.125	106	26.7	-2.1	0.051	28	5.5
6	1	31	31	22	-12.9	0.164	159	29.5	-4.5	0.077	52	8.7
6	1	31	31	23	-9.3	0.138	123	24.0	-3.0	0.065	39	7.5
6	1	31	31	24	-26.9	0.244	290	65.7	-4.4	0.091	66	14.4

Table 7. Affected Hourly Meteorological Variables With and Without u_* Option for HSH Concentration – Inpit Loading/Unloading/Machinery Sources

					Qian and Venkatram				Default			
YR	MO	DY	JDY	HR	H	u_*	Z_{im}	L	H	u_*	Z_{im}	L
5	12	21	355	1	-6.1	0.122	102	25.1	-2.2	0.053	30	5.9
5	12	21	355	2	-3.8	0.121	101	39.4	-0.9	0.034	15	3.7
5	12	21	355	6	-5.1	0.121	101	29.3	-1.6	0.045	23	5.0
5	12	21	355	8	-6.4	0.121	101	23.5	-1.7	0.057	32	8.8
5	12	21	355	9	-6.5	0.121	101	23.0	-1.8	0.058	34	9.0
5	12	21	355	10	-11.6	0.157	150	28.5	-3.4	0.079	53	12.3
5	12	21	355	11	-17.7	0.196	209	42.3	-5.1	0.097	72	15.1
5	12	21	355	12	-21.9	0.219	246	52.9	-8.9	0.107	85	11.9
5	12	21	355	13	-21.9	0.222	252	54.4	-7.8	0.141	127	30.5
5	12	21	355	14	-20.9	0.232	267	59.0	-8.7	0.143	130	28.7
5	12	21	355	15	-18.3	0.206	224	46.5	-6.1	0.101	77	14.2
5	12	21	355	16	-18.1	0.199	213	43.6	-7.4	0.098	74	10.9
5	12	21	355	17	-23.7	0.232	268	59.3	-8.9	0.154	145	35.0
5	12	21	355	18	-14.1	0.175	176	33.5	-4.1	0.087	63	13.6
5	12	21	355	19	-11.6	0.157	150	28.6	-3.4	0.079	53	12.3
5	12	21	355	20	-23.9	0.234	271	60.0	-9.0	0.157	149	36.2
5	12	21	355	21	-17.5	0.195	207	41.7	-5.0	0.096	72	15.0
5	12	21	355	22	-19.0	0.203	220	45.5	-5.5	0.100	76	15.6
5	12	21	355	23	-20.6	0.212	234	49.5	-5.9	0.104	81	16.2
5	12	21	355	24	-7.2	0.123	107	22.0	-2.1	0.063	38	9.7

Table 8. Affected Hourly Meteorological Variables With and Without u_* Option for HSH Concentration – Waste Unloading/Machinery/Hauling Sources

YR	MO	DY	JDY	HR	Qian and Venkatram				Default			
					H	u_*	Z_{im}	L	H	u_*	Z_{im}	L
5	12	26	360	9	-6.1	0.120	100	24.2	-2.3	0.055	31	6.1
5	12	26	360	10	-5.6	0.120	100	26.4	-1.9	0.050	27	5.6
5	12	26	360	11	-6.1	0.120	100	23.9	-2.3	0.055	31	6.1
5	12	26	360	12	-23.5	0.234	271	60.1	-9.9	0.114	92	12.7
5	12	26	360	13	-40.7	0.444	709	216.6	-27.0	0.385	574	179.4
5	12	26	360	14	-8.9	0.143	266	27.6	-2.9	0.072	260	11.0
5	12	26	360	15	-24.0	0.259	315	73.5	-11.5	0.185	192	46.8
5	12	26	360	17	-3.1	0.118	97	43.9	-0.7	0.030	12	3.1
5	12	26	360	18	-4.5	0.120	100	32.9	-0.9	0.040	19	6.3
5	12	26	360	19	-5.7	0.120	100	25.7	-1.6	0.051	28	7.4
5	12	26	360	20	-6.5	0.120	100	22.5	-2.6	0.059	34	6.5
5	12	26	360	22	-9.6	0.143	130	26.1	-3.9	0.073	47	8.3
5	12	26	360	23	-24.3	0.241	284	63.8	-10.5	0.117	96	13.1
5	12	26	360	24	-8.6	0.135	125	24.5	-3.6	0.069	43	7.6

Figure 5. Affected Hourly Meteorological Variables With and Without u_* Option for HSH Concentration - All Sources/Groups

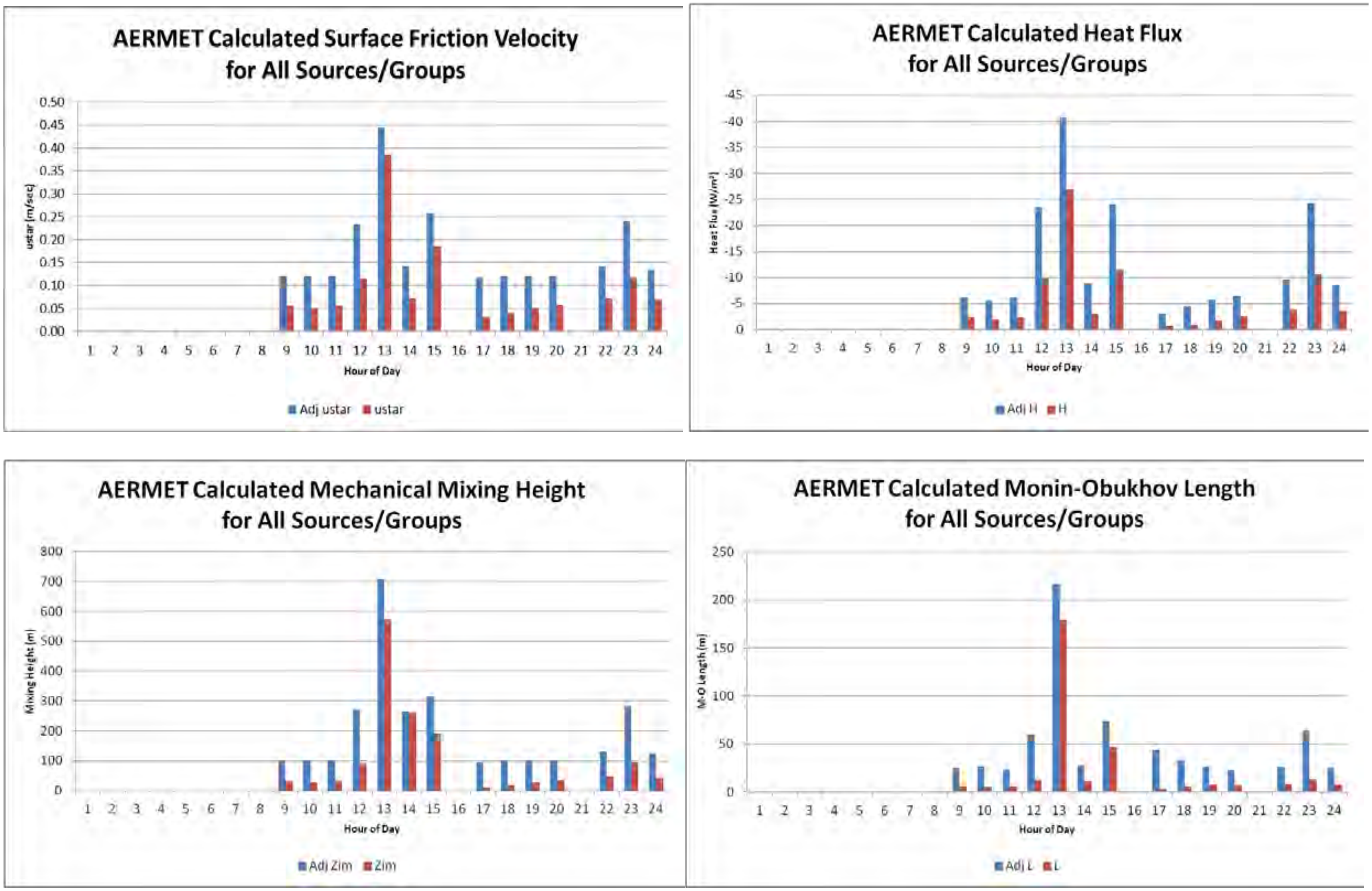


Figure 6. Affected Hourly Meteorological Variables With and Without u_* Option for HSH Concentration – Process and Auxiliary Sources

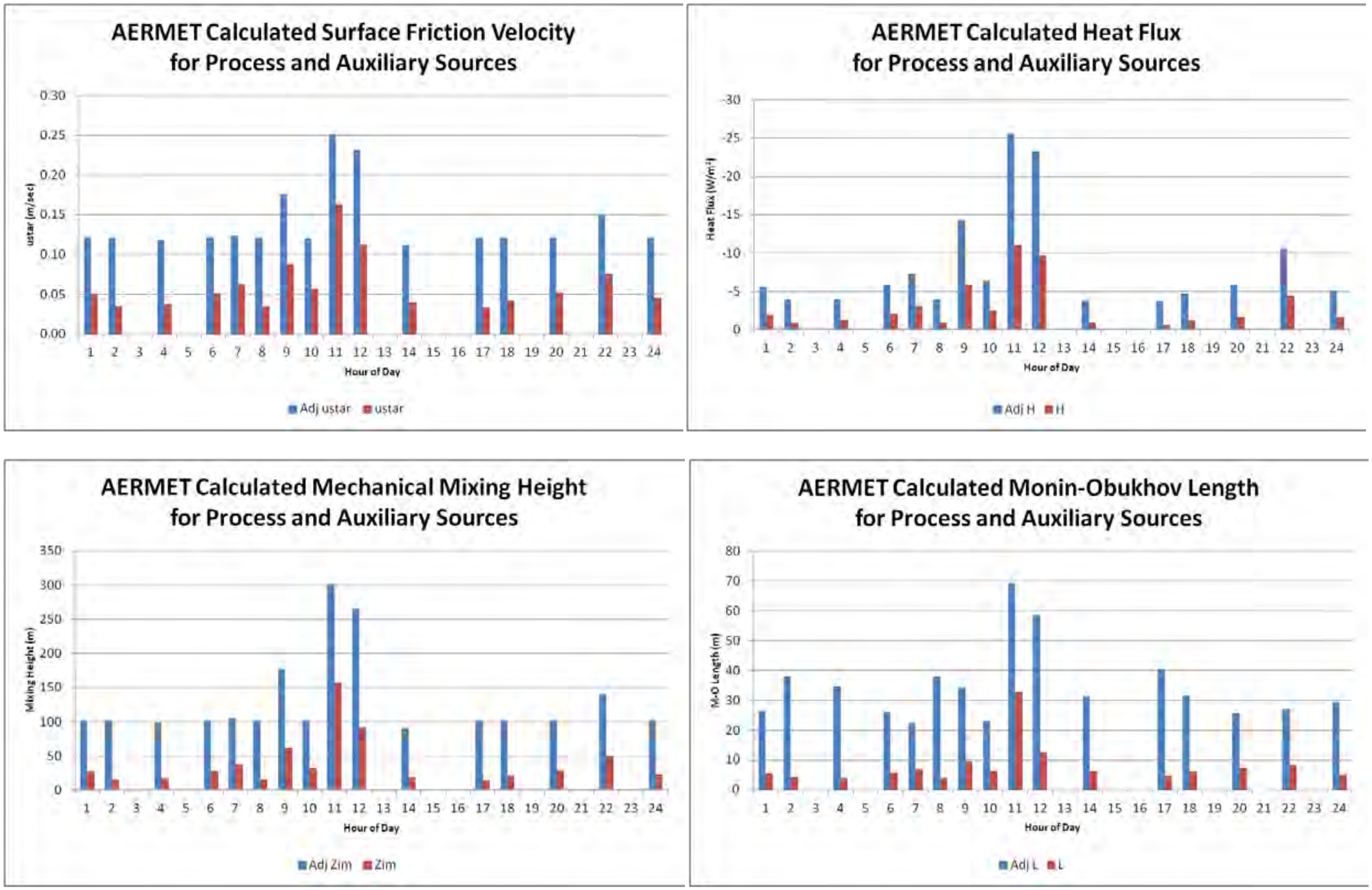


Figure 7. Affected Hourly Meteorological Variables With and Without u_* Option for HSH Concentration – Power Plant Sources

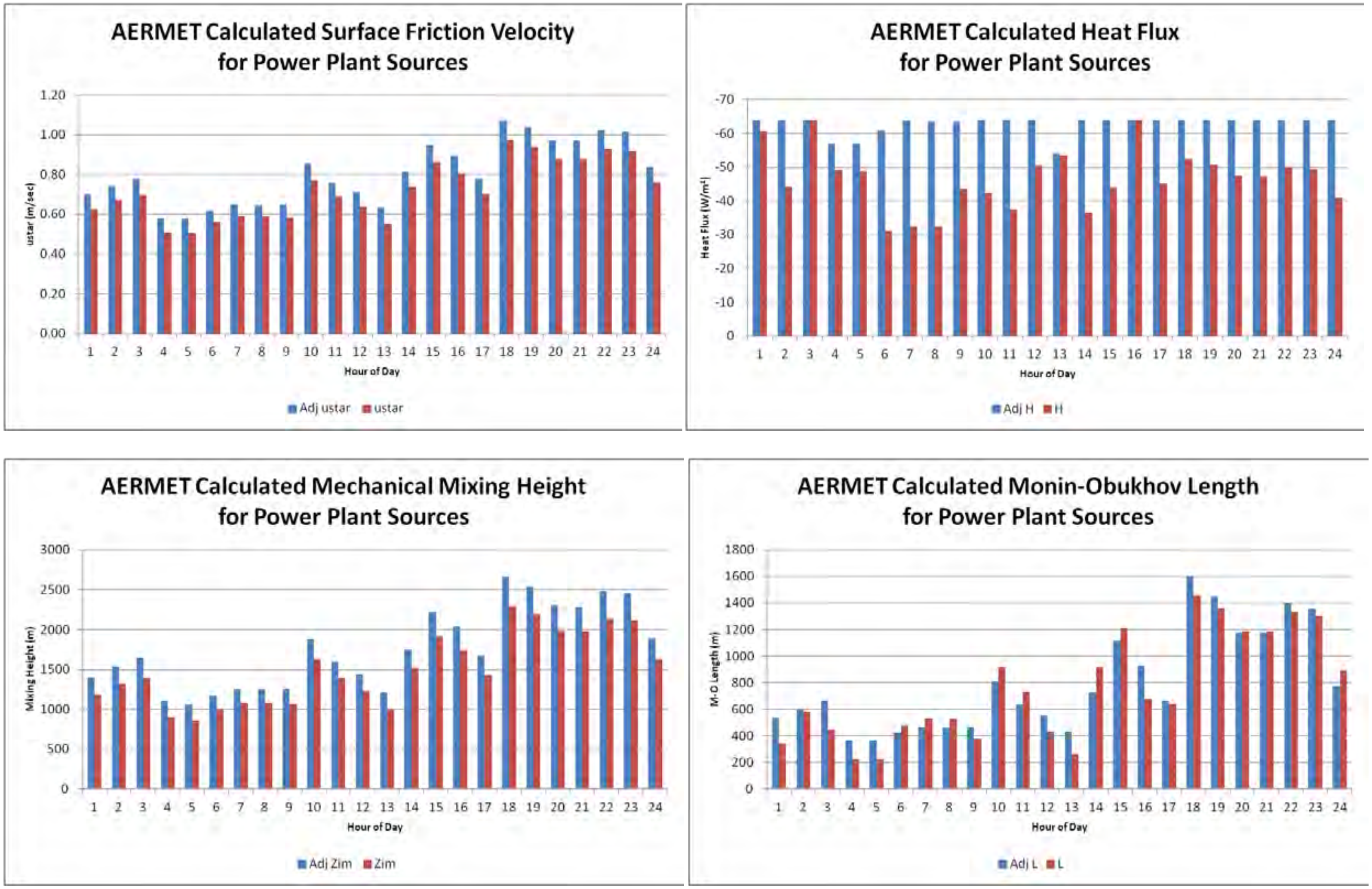


Figure 8. Affected Hourly Meteorological Variables With and Without u. Option for HSH Concentration - Haul Road Sources

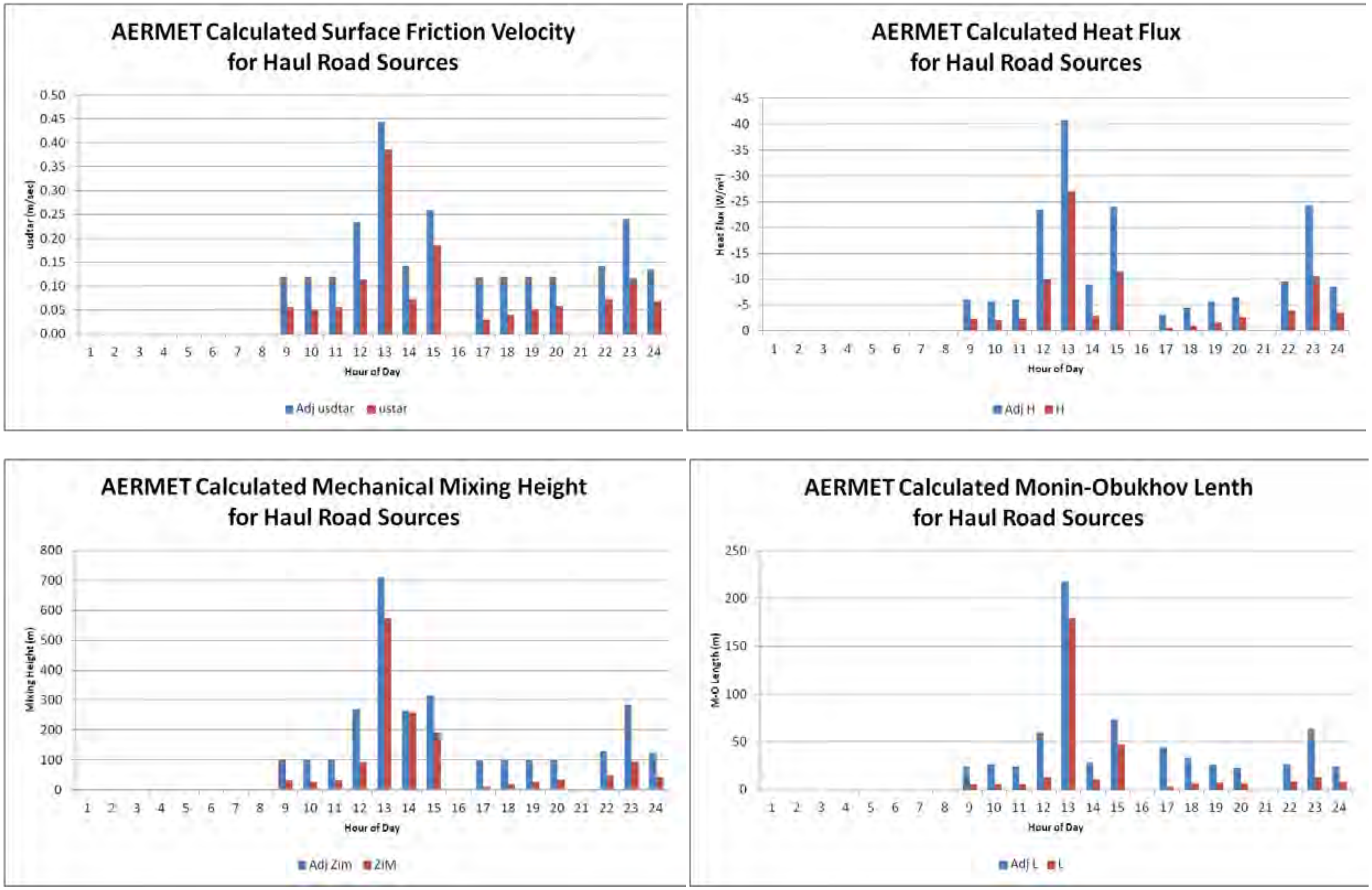


Figure 9. Affected Hourly Meteorological Variables With and Without u. Option for HSH Concentration – Blasting Sources

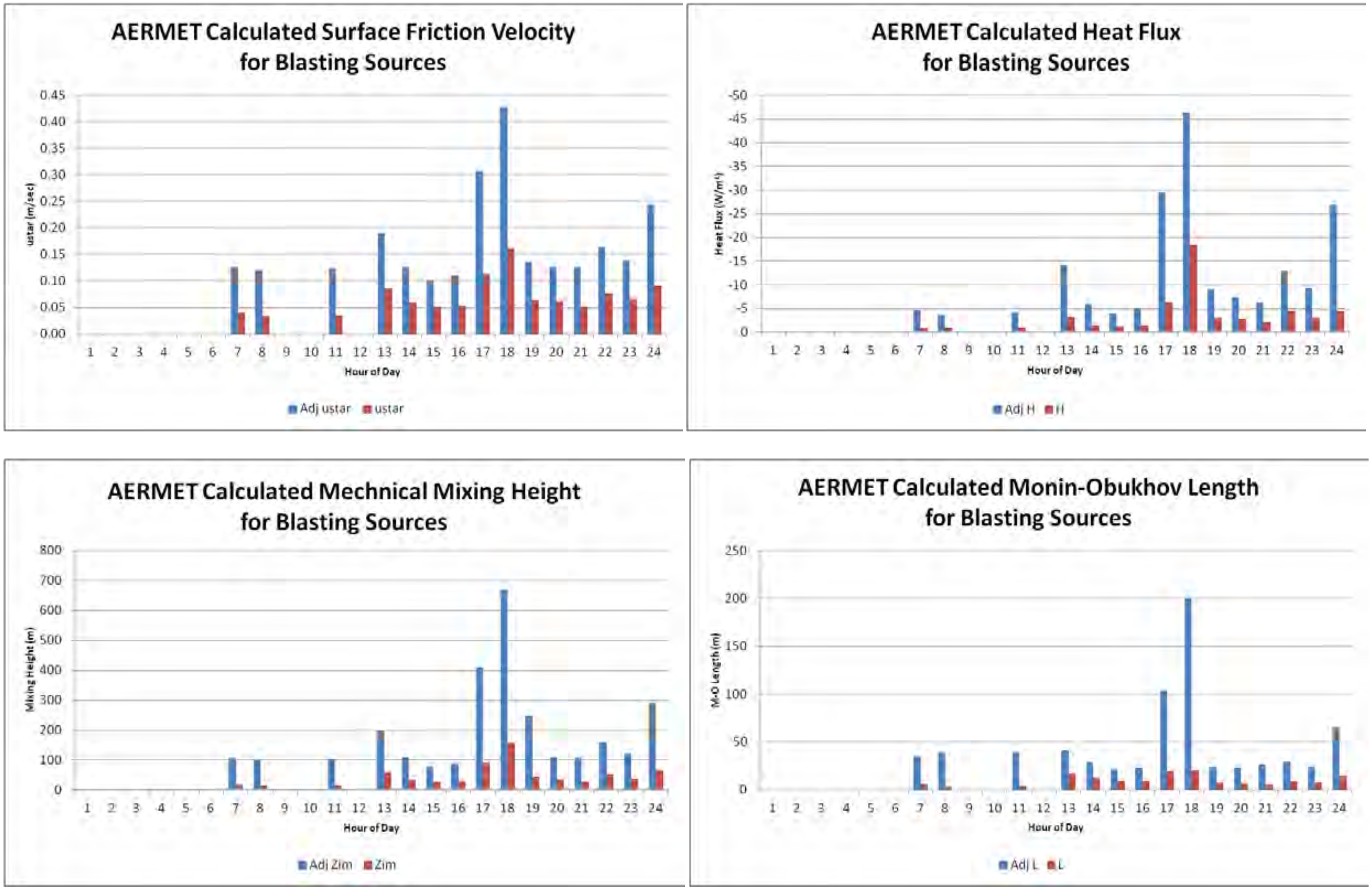


Figure 10. Affected Hourly Meteorological Variables With and Without u_* Option for HSH Concentration – Inpit Loading/Unloading/Machinery Sources

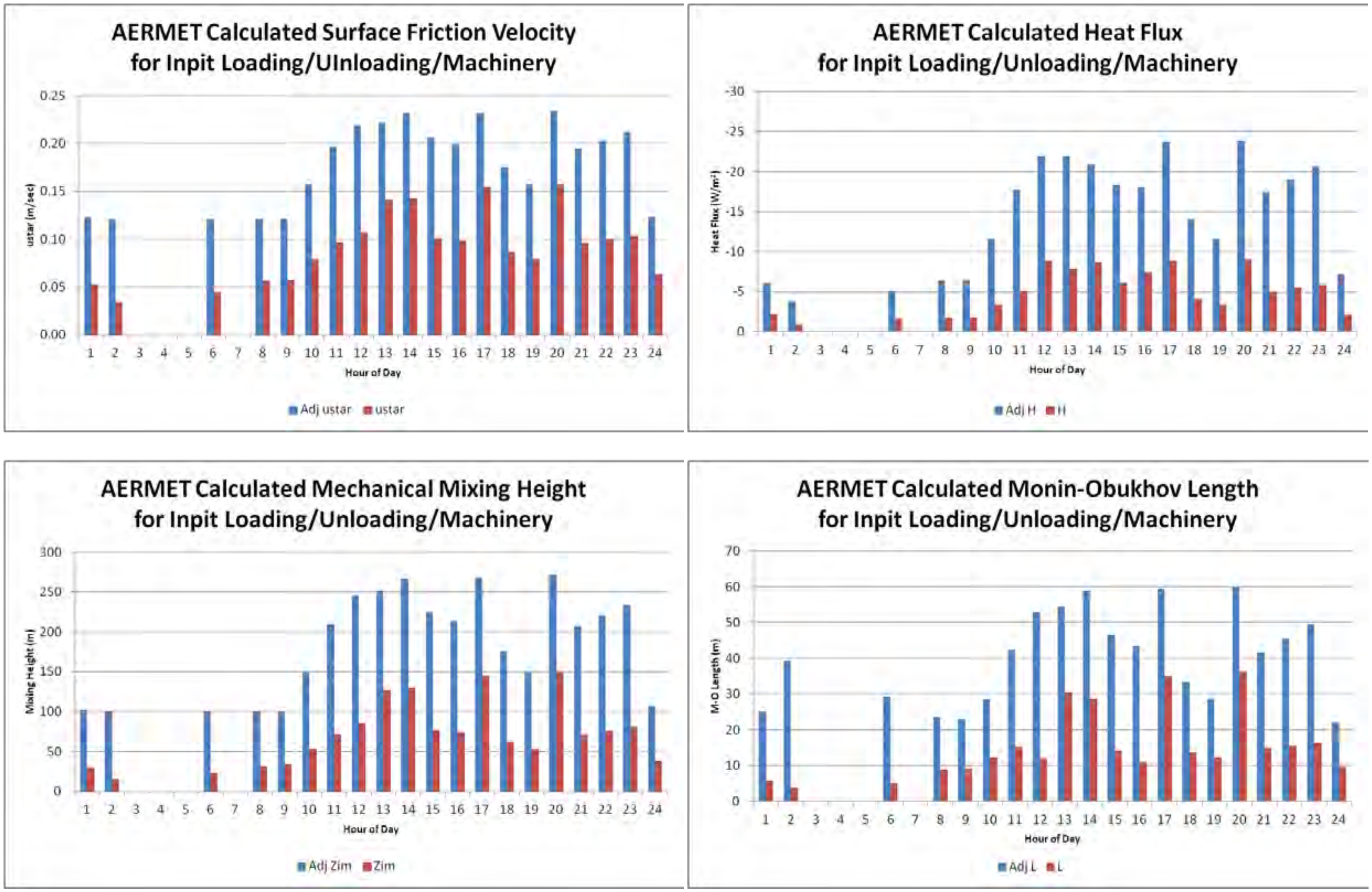
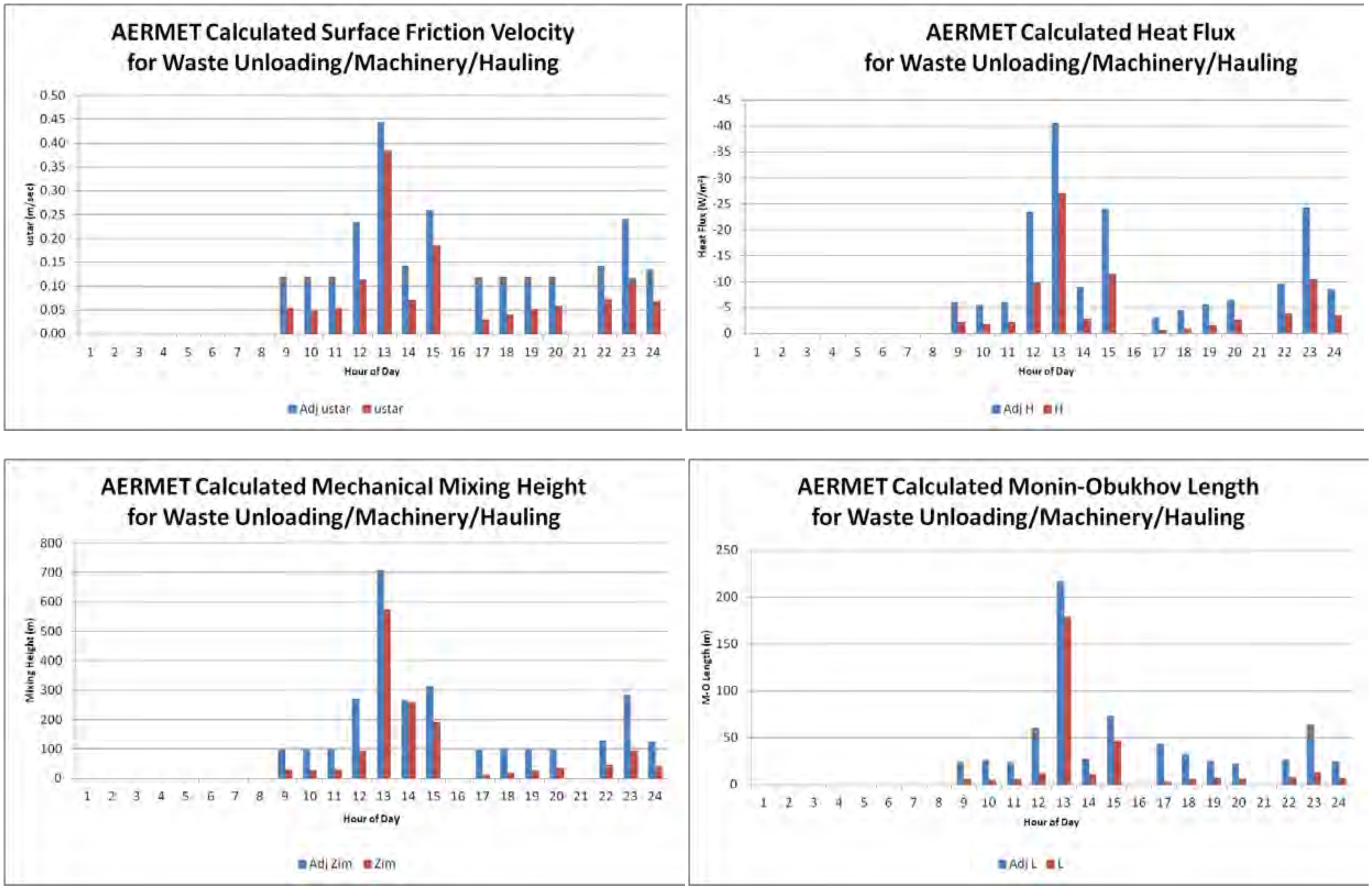


Figure 11. Affected Hourly Meteorological Variables With and Without u_* Option for HSH Concentration – Waste Unloading/Machinery/Hauling Sources



3. Except for the Power Plant Source Group, the u_* option based M-O Length are greater than those based on the Default Method. For Power Plant Source Group, M-O Length based on the Default Method for hours 6, 7, 8, 10, 11, 14, 15, 20, 21, and 24 are greater than the u_* option.
4. Only hours for the HSH day for each of the seven source groups are presented
5. For strong wind cases, the heat flux is set to -64 W/m2 to avoid becoming unrealistically large negatively.

C. Conclusions and Recommendations

C.1 Conclusions

R10 has reviewed the technical materials and presentations available from the Model C/H and the private sector as well the DGLLC technical materials provided to ADEC and R10 and has determined that the condition of Section 3.2.2.d of Appendix W in 40 CFR 51 has been adequately addressed. In addition, while the Qian and Venkatram equations coded into AERMET V15181 addresses the u_* option underpredictions during stable conditions, it also numerically improves the values of heat flux, mechanical mixing height and M-O Length. Thus, AERMET with the u_* option is a better meteorological preprocessor and makes AERMOD a better performing model.

Approval to use this alternative model option is made on a case-by-case basis until a final rulemaking is published in Federal Register that makes the Qian and Venkatram u_* option in Version 15181 a “default option” in AERMOD.

As part of the public notice and comment period, ADEC will solicit comments on the use of the u_* option to support the issuance of the draft PSD permit.

R10 is not aware of any pending AERMOD/AERMET updates, including u_* updates, from EPA. However, ADEC will need to consult with R10 if EPA does issue an update prior to an ADEC public notice of a preliminary permit decision. R10 may recommend that DGLLC revise their analysis if the update corrects a coding error that likely leads to underestimated impacts.

C.2 Recommendations.

Below are two options related to the implementation of the u_* option in AERMET that the Model C/H and R10 developed. DGLLC should select either Model Option 1 or Model Option 2 when preprocessing meteorological data.

Model Option 1 – Use of adjusted u_* (AERMET) with site specific meteorological data that does not include either (1) measured turbulence parameters (i.e., sigma-theta or sigma-w) or (2) beta LOWWIND (AERMOD) options.

Model Option 2 - Use of adjusted u_* (AERMET) with site specific meteorological data that includes measured turbulence parameters and does not include beta LOWWIND (AERMOD) options. Due to the fact that model performance evaluations for the beta LOWWIND (AERMOD) options together with the adjusted u_* option (AERMET) are inconclusive at this time, 1-year of post construction ambient monitoring may be needed should this option be employed.

The Bulk Richardson (AERMET) option can be used with either Option 1 or Option 2.

Table 4 and Figure 7 shows ten hours in which the Default Method M-O Length are greater than the u_* option based M-O Length. The u_* option and related equation in MPPBL and UCALST should be reviewed to determine if changes are necessary.

cc:
Mahbubul Islam, R10
George Bridgers, Model C/H

Attachment A: ADEC Request Letter

THE STATE of ALASKA
GOVERNOR BILL WALKER

Department of Environmental Conservation

DIVISION OF AIR QUALITY
Air Permits Program

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Sent via E-Mail

September 17, 2015

Herman Wong, OEA-140
Office of Environmental Assessment
EPA – Region 10
1200 6th Ave., Suite 900
Seattle, WA 98101

Subject: Request to Use Adjusted_u* Option for the Donlin Gold Project

Dear Mr. Wong:

Through this letter, the Alaska Department of Environmental Conservation (ADEC) is asking the U.S. Environmental Protection Agency (EPA) Region 10 (R10) to allow Donlin Gold LLC (DGLLC) to use EPA's proposed algorithm for adjusting the surface friction velocity (ADJ_u*) within the AERMOD Modeling System. EPA proposed this algorithm as part of their July 29, 2015 revisions to their *Guideline on Air Quality Models* (Guideline).

ADEC will likely issue a preliminary decision on DGLLC's pending Prevention of Significant Deterioration (PSD) permit application before EPA finalizes their proposal. Therefore, DGLLC must follow the requirements in Section 215(c) of Chapter 50 of Title 18 of the Alaska Administrative Code (18 AAC 50.215(c)) to use this non-Guideline technique in their PSD ambient demonstration.

18 AAC 50.215(c)(1) requires applicants to demonstrate in a manner consistent with Section 3.2.2 of the Guideline that the alternative approach is more appropriate than the preferred air quality model. Section 3.2.2 states the request must meet at least one of three conditions, which are summarized below:

1. The alternative and preferred model provide equivalent estimates;

2. The alternative model outperforms the preferred model when comparing the results to actual air quality data; or

3. The preferred model is less appropriate or there is no preferred model for the given scenario.

DGLLC believes their request meets the second criteria. ADEC agrees. As discussed in DGLLC's August 25, 2015 request (enclosed), EPA has noted for the past eight years that AERMOD performs poorly during low wind speed conditions and has been developing the ADJ_u* algorithm since at least 2012 to help mitigate the problem. EPA has now formally proposed the use of this algorithm on a routine basis and has conducted a number of modeled to measured comparisons to support their proposal.

DGLLC conducted a sensitivity analysis to determine which of their emission activities would benefit from the ADJ_u* option. The option provides at least some benefit for all source categories, but the most notable benefit is a 35-percent reduction in the 24-hour coarse particulate (PM-10) impact from haul roads. This source category was included in EPA's Cordero Rojo study, where they determined, "[The] use of the proposed ADJ_U* option in AERMET appears to significantly improve model performance for this study" (EPA's *Proposed Updates to AERMOD Modeling System* presentation at the 11th Modeling Conference). DGLLC's request provides additional information regarding this study, along with other pertinent EPA studies. ADEC has reviewed the sensitivity analysis modeling files and concurs with DGLLC's findings and conclusions.

R10 stated in an August 25, 2015 e-mail[1] that the ADJ_u* option should <u>not</u> be used with the following calculated meteorological parameters: standard deviation of horizontal wind direction (sigma-theta); or standard deviation of vertical wind speed (sigma-w). DGLLC was originally planning to use these parameters but has agreed to exclude them per R10's request.

EPA also proposed a second modeling option (LOWWIND3) that *could be* used in conjunction with the ADJ_u* option, to further mitigate the low wind speed problem. DGLLC is <u>not</u> proposing to use this additional option. The studies presented by EPA show marginal benefits, if any, with the LOWWIND3 option. R10 also stated in their August 25th e-mail that the LOWWIND3 option should not be used since the model performance evaluations "are inconclusive at this time." ADEC agrees that the LOWWIND3 option should not be used at this time.

R10 also raised several preliminary questions regarding DGLLC's request in an August 27, 2015 e-mail.[2] DGLLC provided answers to R10's questions in a September 2, 2015 letter, which is also enclosed.

18 AAC 50.215(c)(2) requires approval from the R10 Administrator and the ADEC Commissioner of a non-Guideline modeling technique. The Commissioner delegated the responsibility for approving non-Guideline modeling methods to the Air Permits Program (APP) Manager on June 3, 2008. It is ADEC's understanding that the R10 Administrator has delegated his authority to you. The APP Manager, John Kuterbach, approved DGLLC's request to use the ADJ_u* algorithm on September 15, 2015. Mr. Kuterbach's approval is enclosed.

In addition to complying with ADEC's modeling requirements in 18 AAC 50.215(c), PSD applicants must also comply with the PSD modeling requirements in 40 CFR 52.21(l), per 18 AAC 50.306(b) and 18 AAC 50.040(h)(10). 40 CFR 52.21(l)(2) says the use of a non-Guideline modeling technique, "must be subject to notice and opportunity for public comment". ADEC will include a notice

[1] Herman Wong (R10) to Alan Schuler (ADEC) and Clint Bowman (Washington Department of Ecology), *R10 – MCH Interactions on Donlin and BP*, August 25, 2015

[2] Herman Wong (R10) to Alan Schuler (ADEC), *Review of Donlin's Request and your Agreement*, August 27, 2015.

regarding DGLLC's use of the ADJ_u* option in the public notice of its preliminary permit decision, if R10 grants DGLLC's request to use this modeling technique and EPA has not yet finalized the ADJ_u* proposal.

For the reasons described above and elaborated on in DGLLC's request, please grant DGLLC permission to use the ADJ_u* option in the ambient demonstration conducted in support of their pending PSD permit application.

If you have any questions regarding this request, please contact me at (623) 271-9028 or at alan.schuler@alaska.gov.

Sincerely,

Alan E. Schuler

Alan E. Schuler, P.E.
Engineer, DEC

Enclosures: DGLLC's August 25, 2015 Request to Use Adjusted_u*
DGLLC's September 2, 2015 Response to R10's Comments
APP Manager Approval to Use Adjusted_u*

cc: Patrick Dunn, ADEC/APP/Anchorage
James Renovatio, ADEC/APP/Juneau
Mike Rieser, DGLLC
Nick Enos, DGLLC

G:\AQ\PERMITS\AIRFACS\Donlin \Construct\Pre-Application\Modeling\Protocol\July 10 2015\u-star Request\EPA ustar Request 091715.docx

Attachment B: DGLLC 25 August 2015 Letter

August 25, 2015

Mr. Alan Schuler
Division of Air Quality
Alaska Department of Environmental Conservation
410 Willoughby, Suite 303
PO Box 111800
Juneau, AK 99811-1800

RE: Additional Information Regarding DGLLC's ADJ_U* Approval Request

Dear Mr. Schuler,

In previous submittals, Donlin Gold LLC (DGLLC) has sought approval from the Alaska Department of Environmental Conservation (ADEC) and the U.S. Environmental Protection Agency (EPA) Region 10 (R10) for the use of a non-default adjusted surface friction velocity (ADJ_U*) option in the AERMOD modeling for its proposed Donlin project in southwestern Alaska.[1] With this submittal, DGLLC is updating this approval request as described in this letter.

Recently EPA has released a new version of its regulatory default AERMOD modeling system (v15181). EPA is also seeking and reviewing public comments on its proposed changes to the Guideline on Air Quality Models (40 CFR Part 51, Appendix W). In the wake of these developments, EPA R10 and ADEC have requested that DGLLC update its pending ADJ_U* approval request to include and/or address relevant AERMOD and 40 CFR 51, Appendix W revisions. In addition, ADEC has requested that DGLLC perform a model sensitivity study to evaluate the effects of the ADJ_U* option with the new AERMOD modeling system v15181 for its Donlin project.

This letter provides a summary of updates to DGLLC's ADJ_U* approval request and the ADJ_U* sensitivity analysis with AERMOD v15181 for the Donlin project.

It is important to note that EPA's proposal to incorporate ADJ_U* as a default regulatory option is currently under public review and comment (EPA 2015c, EPA 2015d). EPA has acknowledged that AERMOD performs poorly during low wind-speed conditions (Robinson and Brode 2007). To address this concern, EPA has evaluated the technical basis of the ADJ_U* option and has completed several model evaluation studies. The results of these evaluation studies conclude that the ADJ_U* option produces statistically significant improvement in AERMOD performance compared to the default option (EPA 2014).

[1] The original request was submitted to EPA R10 in April 2014; it was revised and re-submitted in July 2014, and additional information was provided in October of 2014.

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Tel (907) 273-0200 Fax (907) 273-0201 www.DonlinGold.com

Updated ADJ_U* Approval Request

DGLLC's revised ADJ_U* approval request for its Donlin project, dated August 24, 2015, is provided in Attachment A for ADEC's review. The criteria for approval of an alternate model are set forth in 40 CFR 51, Appendix W, Sections 3.2.2.b. through e. DGLLC has reviewed EPA's recent proposed changes to 40 CFR 51, Appendix W, and the relevant changes are addressed in the revised ADJ_U* approval request provided in Attachment A. Although DGLLC is currently required to request EPA's approval of an alternate model for the use of the ADJ_U* option, pending EPA's review of public comments related to this option, it is expected that ADJ_U* will be incorporated as a default regulatory option for AERMOD modeling (EPA 2015c, EPA 2015d).

The new AERMOD v15181 background and technical support documentation, updated user's guides (EPA 2015a, EPA 2015b), test cases, and codes/executables have been provided by EPA on the Support Center for Regulatory Atmospheric Modeling (SCRAM) webpage. Per EPA R10's request, DGLLC has reviewed this documentation and has incorporated relevant material in its revised ADJ_U* approval request provided in Attachment A.

With the release of AERMOD v15181, EPA updated the ADJ_U* field study validations (EPA 2015b) using this version for the following evaluation databases: Oak Ridge, Idaho Falls, and Lovett. EPA has not updated the recently released Cordero Rojo surface coal mine ADJ_U* evaluation study with AERMOD v15181. However, EPA states that it expected that the ADJ_U* evaluation results for the Cordero Rojo study "are likely to be similar for v15181" (EPA 2015d). The Cordero Rojo study is particularly applicable to the Donlin project because of the similarity of source and emission characteristics. These four evaluation studies show that the AERMOD model performance improved significantly with the use of ADJ_U*. Therefore, DGLLC continues to assert that EPA's existing model evaluation studies for ADJ_U* provide comprehensive and sufficiently appropriate support documentation to justify DGLLC's proposed use of ADJ_U* for the Donlin project.

ADJ_U* Sensitivity Modeling with AERMOD v15181

EPA R10 suggested that DGLLC perform an ADJ_U* sensitivity analysis using AERMOD v15181 and the Alaska tracer gas experiment provided on SCRAM. However, DGLLC and ADEC believe that the Alaska tracer study available on SCRAM will not provide evaluations that are representative of the Donlin project because the study was performed for a source in a flat-terrain, coastal setting, whereas the Donlin project is located inland in complex terrain. Furthermore, the Alaska tracer study only considered daytime hours with typically higher wind speeds and emissions from a tall stack, which are not related to the ADJ_U* option. DGLLC is not aware of additional EPA model tracer studies performed for low-release emissions and stable conditions in a complex terrain Alaskan environment.

EPA R10 initially suggested testing building downwash and NO_X chemistry modules for ADJ_U* with AERMOD v15181 for the Donlin project. However, ADEC suggested (and DGLLC concurs) that the sensitivity analysis should only focus on the most relevant aspects of modeling associated with ADJ_U*. The preliminary analyses performed for the Donlin project suggest that its primary ambient air impact issues are related to particulate concentrations from low-release fugitive emission sources occurring under low wind-speed conditions. Building downwash and NO_X

chemistry options are less pertinent to Donlin project impacts. DGLLC is not aware of any model performance issues that have arisen from the application of ADJ_U* with downwash or NO_X chemistry modules.

The application of the ADJ_U* option reduces the frequency of low surface friction velocity (u*) values that are known to result in over-predictions of modeled concentrations with AERMOD. Figure 1 provides a comparison of the u* values estimated by the AERMOD meteorological preprocessor AERMET v15181 using the default and ADJ_U* options for five years of DGLLC American Ridge meteorological station data.

Figure 1. Comparison of u* Values with AERMET Default and ADJ_U* Options: American Ridge Data Set (July 1, 2005 – June 30, 2010)

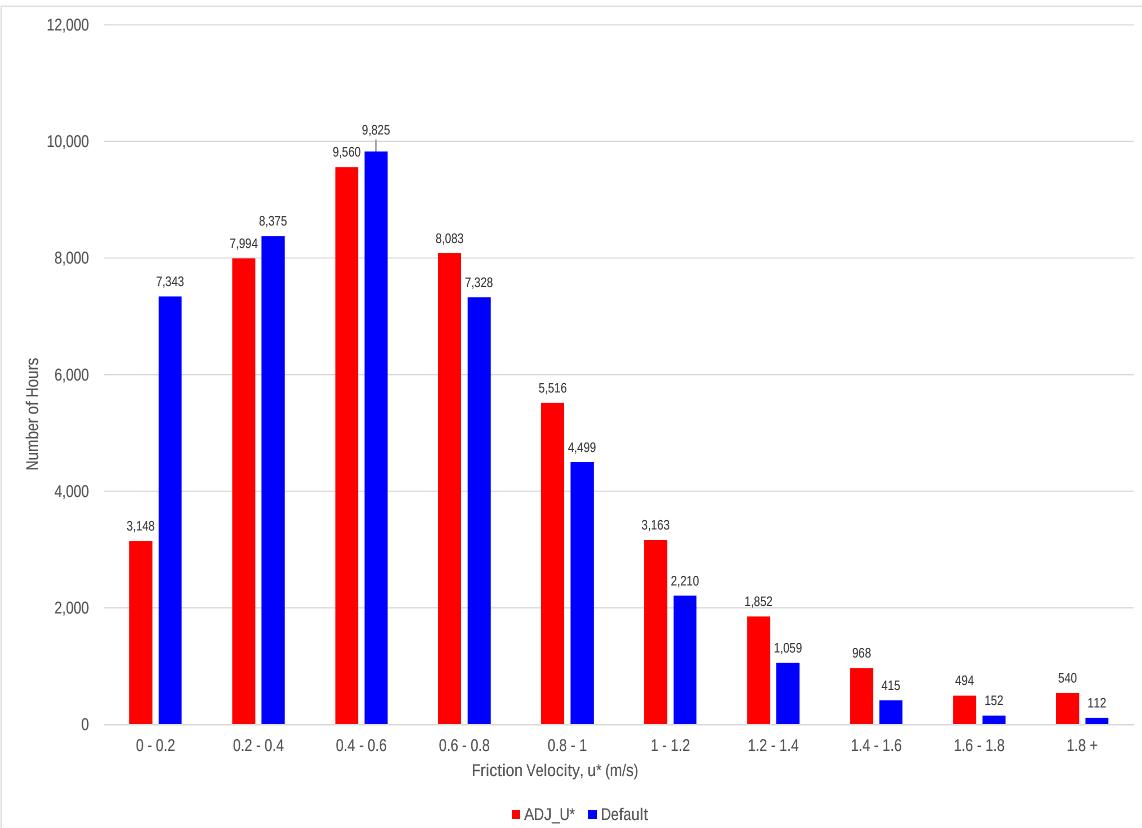


Figure 1 shows that the ADJ_U* option significantly reduces (from 7,343 to 3,148) the occurrence of low u* values (up to 0.2 meters per second) when applied for the American Ridge data set.

Following ADEC's suggestion, the AERMOD v15181 sensitivity study described herein includes the following:

- Six project-specific source groups (listed in Table 1) that are expected to significantly influence the modeled concentrations (based on preliminary analyses)

- 24-hour PM_{10} emissions and modeling options
- One year (2005) of the worst-case site-specific (American Ridge) meteorological data set, which excludes site-specific sigma data for the ADJ_U* option
- One ambient air receptor in a location at or near the maximum 24-hour PM_{10} design concentration (high-second-high [H2H]) as determined from preliminary analyses

The H2H 24-hour PM_{10} results of the Donlin project's ADJ_U* sensitivity analysis are summarized in Table 1.

Table 1. Summary of Donlin Project's ADJ_U* Sensitivity Modeling

	H2H 24-hour PM_{10} Concentration ($\mu g/m^3$)	
Source Group Description	Default	ADJ_U*
Process and Ancillary Sources, Excluding Power Plant	7.70	2.87
Power Plant	0.77	0.59
All Haul Roads	21.15	13.78
Blasting	2.48	1.42
In-pit, Excluding Hauling and Blasting	9.44	4.49
Waste Rock Storage	3.15	1.35

As shown in Table 1, results of the sensitivity analysis indicate that the use of ADJ_U* reduces maximum 24-hour PM_{10} modeled concentrations. The results of this analysis also highlight that the low-release, fugitive haul road emissions are expected to be the most significant contributor to the Donlin project's overall PM_{10} impacts. When applying ADJ_U*, the largest concentration reduction (7.4 $\mu g/m^3$) is associated with the haul roads.

The modeled 24-hour PM_{10} concentration plots for each source group listed in Table 1 are provided in Figures 2 through 7. These plots present the modeled concentrations (364 values starting with the H2H) for both default and ADJ_U* cases, as a function of 24-hour average u* values.

Figure 2. 24-Hour Modeled Concentrations vs. u* Values – Source Group: Process and Ancillary Sources, Excluding Power Plant

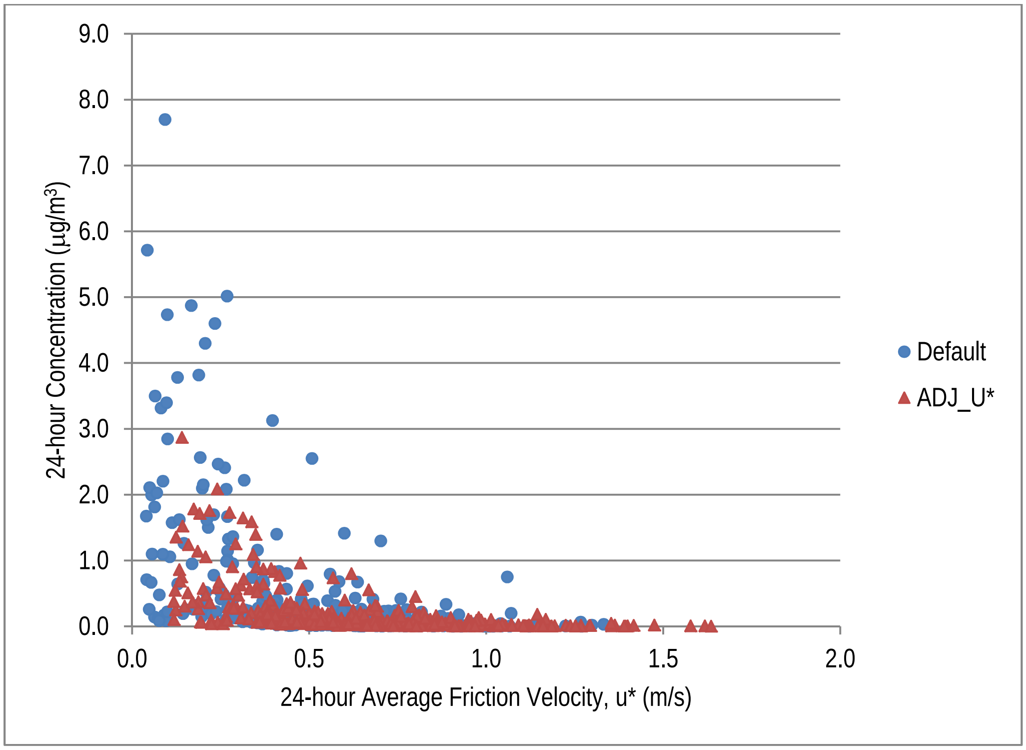


Figure 3. 24-Hour Modeled Concentrations vs. u* Values – Source Group: Power Plant

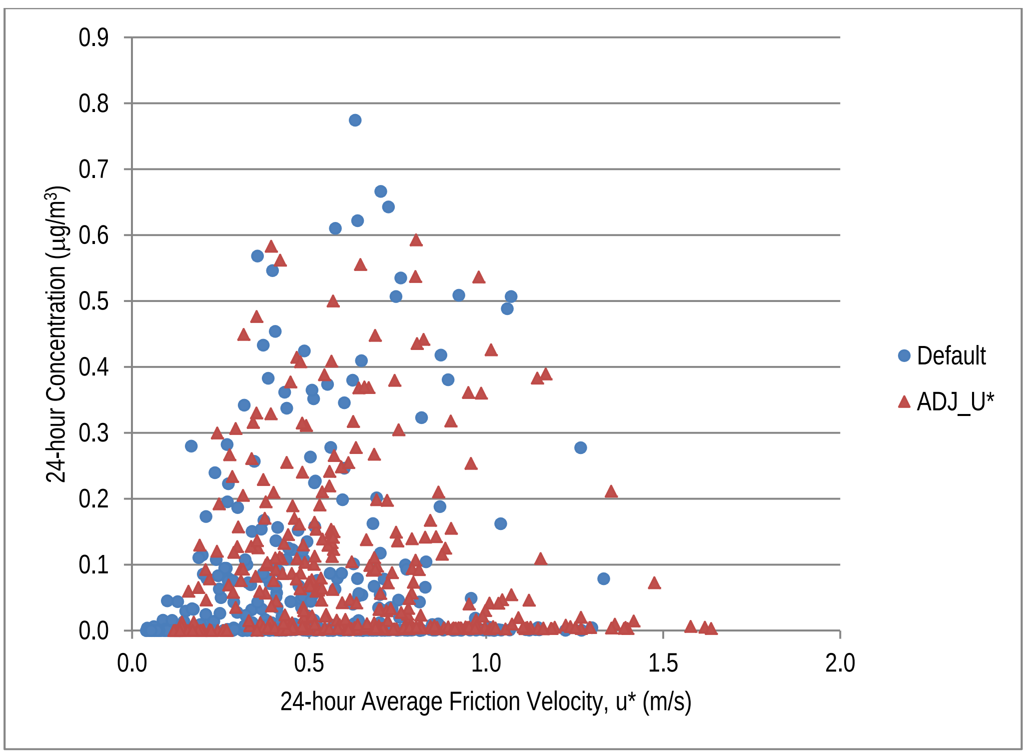


Figure 4. 24-Hour Modeled Concentrations vs. u* Values – Source Group: All Haul Roads

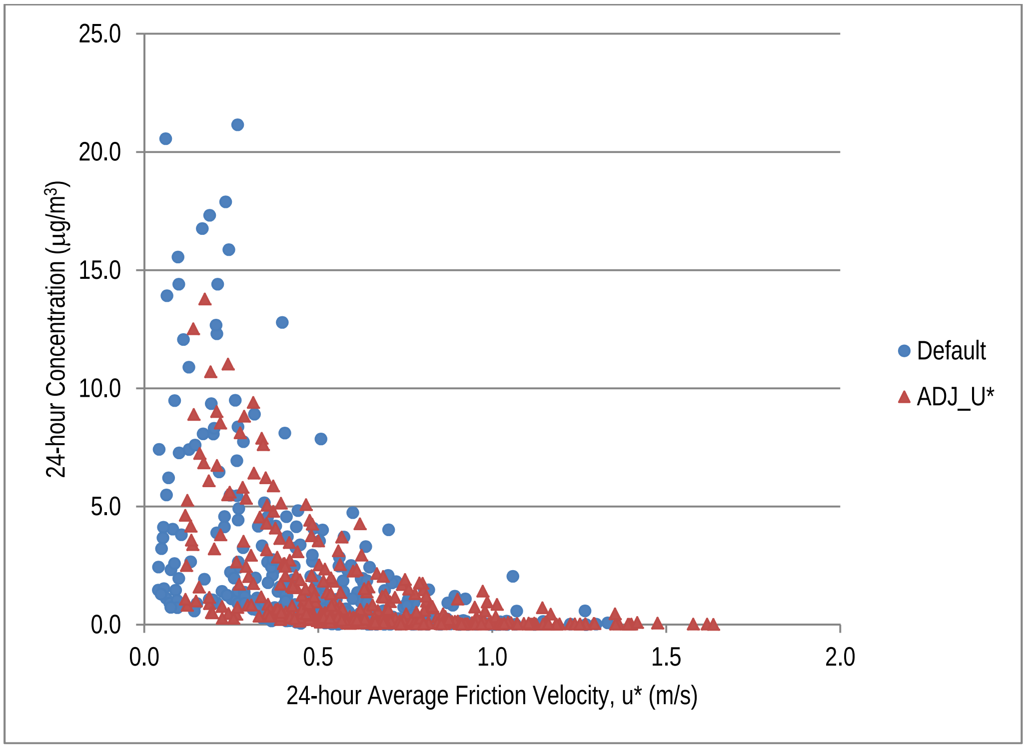


Figure 5. 24-Hour Modeled Concentrations vs. u* Values – Source Group: Blasting

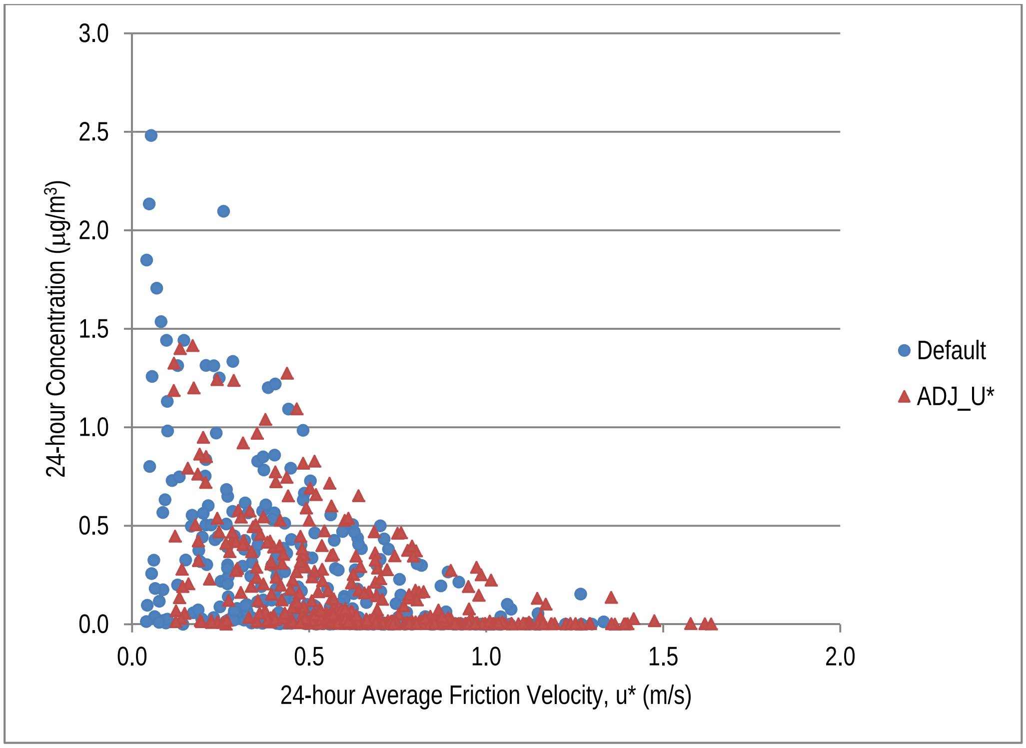


Figure 6. 24-Hour Modeled Concentrations vs. u* Values – Source Group: In-pit, Excluding Hauling and Blasting

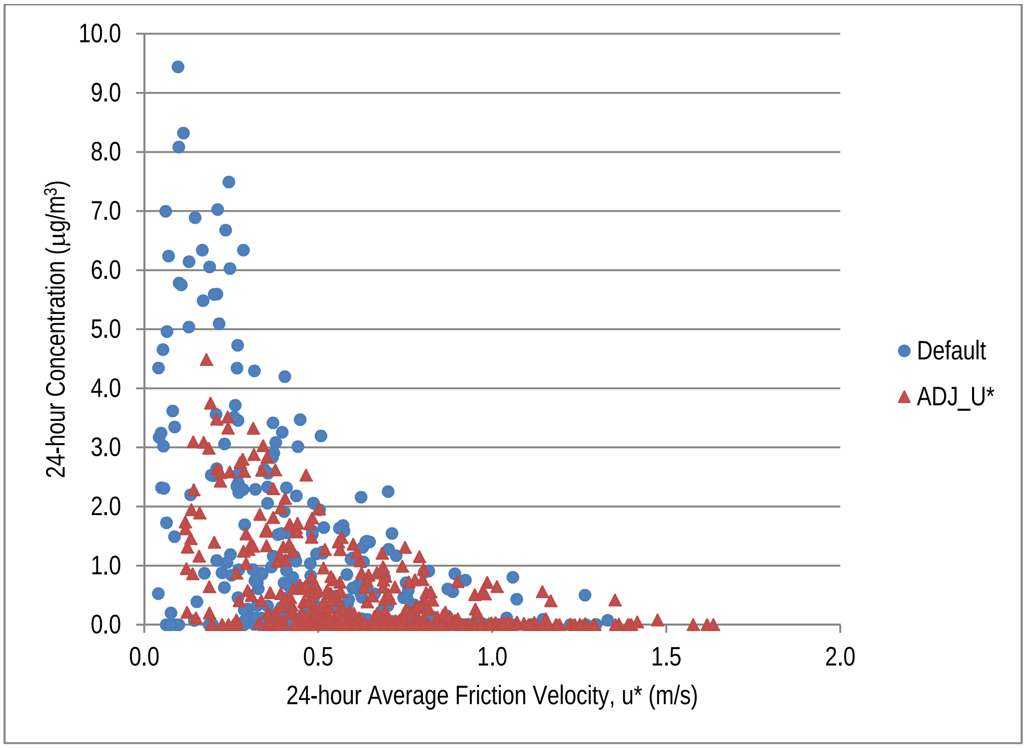
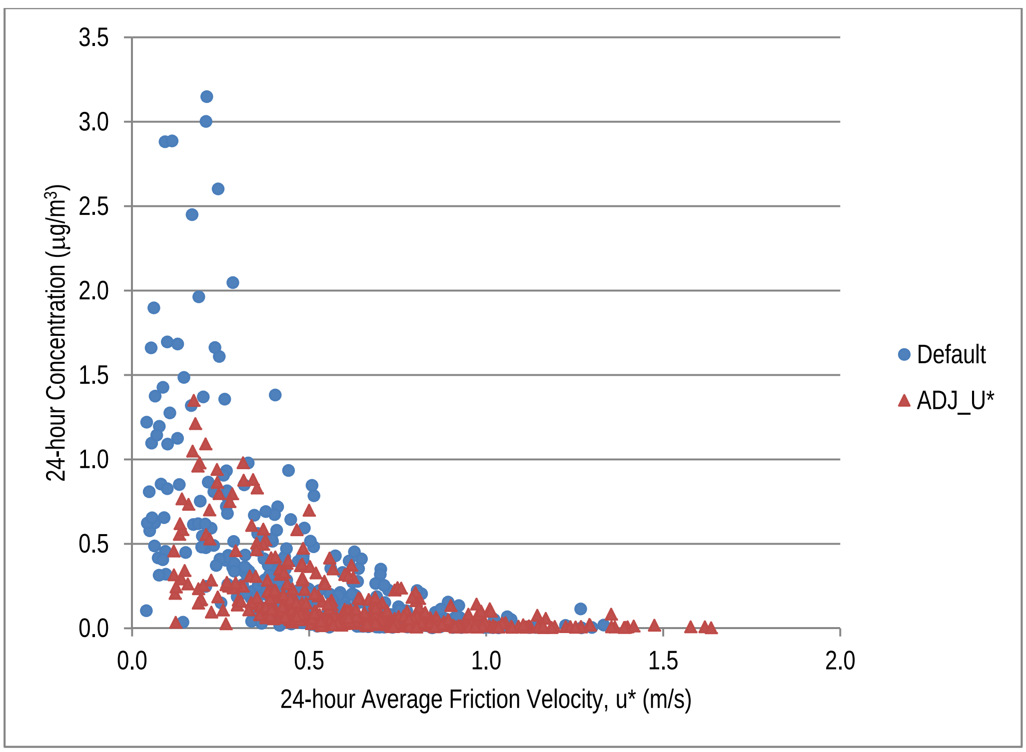


Figure 7. 24-Hour Modeled Concentrations vs. u* Values – Source Group: Waste Rock Storage



DGLLC asserts that application of the ADJ_U* option for the Donlin project is appropriate and essential in order to predict reasonable modeled impacts, due to prevailing low wind-speed conditions and dominant low-release emissions. As shown in this analysis, the use of the ADJ_U* option with AERMOD v15181 significantly reduces the frequency of low u* values, which are known to contribute to unreasonably high modeled concentrations.

Please contact me should you have any questions or require additional information.

Sincerely,

Michael Rieser
Senior Environmental Engineer

Attachments:

Attachment A – Request for Approval to use ADJ_U*

cc by e-mail:

Patrick Dunn, Division of Air Quality, ADEC
James Renovatio, Division of Air Quality, ADEC
Robert (Nick) Enos, Donlin Gold LLC

References

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TECHNICAL MEMORANDUM

REQUEST FOR APPROVAL TO USE ADJ_U*

PREPARED FOR: Alaska Department of Environmental Conservation

PREPARED BY: Donlin Gold LLC and Air Sciences Inc.

PROJECT NO.: 281-15-2

DATE: August 25, 2015

TABLE OF CONTENTS

1.0 Introduction

The purpose of this memorandum is to seek approval from the Alaska Department of Environmental Conservation (ADEC) and the U.S. Environmental Protection Agency (EPA) for application of the non-default adjusted surface friction velocity (ADJ_U*) option in the AERMOD modeling for Donlin Gold LLC's (DGLLC) proposed Donlin project in southwestern Alaska. This request is submitted pursuant to Section 3.2 of the Guideline on Air Quality Models (the Guideline; EPA 2005). Additionally, the July 29, 2015, proposed revisions to Section 3.2 of the Guideline (EPA 2015e) regarding the ADJ_U* option are addressed in this memorandum.

DGLLC believes that the application of the ADJ_U* option is appropriate in the AERMOD modeling analysis for the Donlin project because of the frequent occurrence of low wind speed stable conditions, under which the default option (i.e., no low wind-speed correction) in

AERMOD is known to over-predict ambient concentrations. The ADJ_U* option is intended to significantly improve AERMOD's performance, compared to the default option, including the performance for sites and sources similar to the Donlin project where emissions are released at low heights (typical of surface mining sources) and the project is located in a region with complex terrain.

2.0 Background

2.1 ADJ_U* Intended as Regulatory Default Option

In the proposed revisions to the Guideline (EPA 2015e), EPA intends for the ADJ_U* option to be part of the regulatory default model. EPA made this proposal in the preamble to the proposed changes to the Guideline, referred to below as Notice of Public Rule Making (NPRM). Due to several initial comments from stakeholders, members of the EPA modeling group provided clarifications (EPA 2015c and 2015d) that reinforced EPA's intent to include ADJ_U* as a regulatory default option. These clarifications were provided during EPA's 11th Conference on Air Quality Modeling and Public Hearing for the Proposed Revisions to the Guideline held on August 12–13, 2015 (2015 Conference). EPA's statements regarding the ADJ_U* option as presented in the NPRM and the 2015 Conference are provided below.

From NPRM section IV.A.2., "Updates to EPA's AERMOD Modeling System" (EPA 2015e):

> *"Based on studies presented and discussed at the Tenth Modeling Conference, and additional relevant research since 2010, the EPA and other researchers have conducted additional model evaluations and developed changes to the model formulation of the AERMOD modeling system to improve model performance in its regulatory applications. We propose the following updates to the AERMOD modeling system to address a number of technical concerns expressed by stakeholders:*
>
> 1. *A proposed option incorporated in AERMET to adjust the surface friction velocity (u*) to address issues with AERMOD model overprediction under stable, low wind speed conditions. This proposed option is selected by the user with the METHOD STABLEBL ADJ_U* record in the AERMET Stage 3 input file."*

As presented on the public record at the 2015 Conference by Tyler Fox in his presentation "Overview of Proposed Revisions to Appendix W" (EPA 2015c):

> *"In the NPRM, EPA has proposed to incorporate specific updates to the regulatory version that are the subject of public review and comment and then would be codified as part of the final rule action, as appropriate.*
>
> *– These options have thus remained "beta" in v15181 to allow for public testing & evaluation"*

As presented on the public record at the 2015 Conference by Roger Brode in his presentation "Proposed Updates to AERMOD Modeling System" (EPA 2015d):

> *"EPA has proposed in the NPRM that the ADJ_U* option (with or without BULKRN) be incorporated into the regulatory version of AERMET."*

It is clear that EPA, pending review and comments during the public comment period, intends to incorporate ADJ_U* as a regulatory default option. At this time, ADJ_U* remains a non-default option and requires approval from EPA for use in modeling compliance demonstrations. According to statements at the 2015 Conference, the proposed revisions to the Guideline are expected to be finalized by the spring of 2016 (EPA 2015c).

2.2 Development of ADJ_U* to Improve AERMOD Performance

EPA has acknowledged poor AERMOD performance during low wind-speed conditions (Robinson and Brode 2007). Qian and Venkatram (2010) demonstrated that the AERMOD meteorological preprocessor (AERMET) tends to grossly under-predict surface friction velocity (u*) under low wind-speed conditions (less than two meters per second). When simulating low release height emission sources with AERMOD, the under-prediction of u* leads to inappropriately low mechanical mixing heights, consequently resulting in overly conservative (excessively high) ambient concentration estimations (EPA 2015b; Paine and Connors 2013; Qian and Venkatram 2010).

Qian and Venkatram (2010) suggested a new method for calculating u* and showed results that support improved u* and model concentration predictions in the low wind-speed regime. EPA has incorporated this calculation methodology in AERMET as ADJ_U* (EPA 2013), most recently in AERMET version 15181. The ADJ_U* method is a processing option for calculating u* for low wind speeds during stable (nighttime) conditions (EPA 2015a). Several study results support the conclusion that the application of the ADJ_U* option significantly improves AERMOD performance for low wind-speed conditions while maintaining a conservatively high bias in predicted concentrations (EPA 2013; EPA 2015b; EPA 2014; Paine and Connors 2013). These studies indicate that the ADJ_U* option has been sufficiently peer-reviewed.

2.3 Donlin Project Characteristics

The proposed Donlin project is located in the Yukon–Kuskokwim region of southwestern Alaska, a remote, mountainous area. It is approximately 280 miles west of Anchorage, 155 miles northeast of Bethel, and 10 miles north of the village of Crooked Creek. The project area is one of low topographic relief on the western flank of the Kuskokwim Mountains. Elevations in the project area range from 500 to 2,100 feet.

Typically, air quality analyses for surface mine projects like Donlin are predominantly driven by fugitive emissions associated with mining activities such as material extraction and hauling; mobile machinery tailpipes; maintenance equipment; and wind erosion of exposed surfaces. Activities like these are characterized in AERMOD by emission sources with low release heights (less than 10 meters).

The use of the ADJ_U* option is particularly appropriate when processing meteorological data at high-latitude Alaskan sites, due to the long winter nights and frequent cloudy conditions that tend to cause sustained low wind speeds and stable conditions. For the meteorological data proposed for the Donlin project air quality analysis, 22.4 percent of the hourly wind speeds are less than two meters per second, and over 50 percent of these low wind speeds occur during the winter months.

3.0 Request for ADJ_U* Approval

3.1 Guideline Criteria for Alternative Models

The criteria for approval of an alternative model are set forth in Sections 3.2.2(b) through (e) of the Guideline (EPA 2005), which state the following:

> "*b. An alternative model should be evaluated from both a theoretical and a performance perspective before it is selected for use. There are three separate conditions under which such a model may normally be approved for use: (1) If a demonstration can be made that the model produces concentration estimates equivalent to the estimates obtained using a preferred model; (2) if a statistical performance evaluation has been conducted using measured air quality data and the results of that evaluation indicate the alternative model performs better for the given application than a comparable model in Appendix A; or (3) if the preferred model is less appropriate for the specific application, or there is no preferred model. Any one of these three separate conditions may make use of an alternative model acceptable. Some known alternative models that are applicable for selected situations are listed on EPA's SCRAM Internet Web site (subsection 2.3). However, inclusion there does not confer any unique status relative to other alternative models that are being or will be developed in the future.*
>
> *c. Equivalency, condition (1) in paragraph (b) of this subsection, is established by demonstrating that the maximum or highest, second highest concentrations are within 2 percent of the estimates obtained from the preferred model. The option to show equivalency is intended as a simple demonstration of acceptability for an alternative model that is so nearly identical (or contains options that can make it identical) to a preferred model that it can be treated for practical purposes as the preferred model. Two percent was selected as the basis for equivalency since it is a rough approximation of the fraction that PSD Class I increments are of the NAAQS for SO_2, i.e., the difference in concentrations that is judged to be significant. However, notwithstanding this*

demonstration, models that are not equivalent may be used when one of the two other conditions described in paragraphs (d) and (e) of this subsection are satisfied.

d. For condition (2) in paragraph (b) of this subsection, established procedures and techniques[…] for determining the acceptability of a model for an individual case based on superior performance should be followed, as appropriate. Preparation and implementation of an evaluation protocol which is acceptable to both control agencies and regulated industry is an important element in such an evaluation.

e. Finally, for condition (3) in paragraph (b) of this subsection, an alternative refined model may be used provided that:

i. The model has received a scientific peer review;

ii. The model can be demonstrated to be applicable to the problem on a theoretical basis;

iii. The data bases which are necessary to perform the analysis are available and adequate;

iv. Appropriate performance evaluations of the model have shown that the model is not biased toward underestimates; and

v. A protocol on methods and procedures to be followed has been established."

DGLLC asserts that its request to use the ADJ_U* option in the AERMOD modeling system can be considered under either Section 3.2.2(b)(2) or 3.2.2(b)(3) for the Donlin project under the current Guideline rules (EPA 2005). Section 3.2.2(b)(3) of the current Guideline (EPA 2005) and of the proposed Guideline revisions (EPA 2015e) lists one of the conditions under which an alternative model may be approved. Under the current Guideline (EPA 2005), Section 3.2.2(b)(3) reads:

"(3) if the preferred model is less appropriate for the specific application, or there is no preferred model."

In the proposed revisions (EPA 2015e), Section 3.2.2(b)(3) reads:

"(3) If there is no preferred model."

Given the language changes in the proposed revisions (EPA 2015e), DGLLC is not considering Section 3.2.2(b)(3) for this request.

However, the request for ADJ_U* can still be considered under 3.2.2(b)(2), which is the same under the current Guideline (EPA 2005) and the proposed Guideline revisions (EPA 2015e).

Thus, until EPA approves ADJ_U* as the default option in AERMOD, DGLLC requests EPA's approval of the use of ADJ_U* under condition 3.2.2(b)(2).

3.2 Request for Approval Under Section 3.2.2(b)(2)

Sections 3.2.2(b)(2) and 3.2.2(d) of the current Guideline (EPA 2005) state the following criteria for alternative model approval:

> 3.2.2(b)(2):
> *"if a statistical performance evaluation has been conducted using measured air quality data and the results of that evaluation indicate the alternative model performs better for the given application than a comparable model in Appendix A;"*
>
> 3.2.2(d):
> *"For condition (2) in paragraph (b) of this subsection, established procedures and techniques[…] for determining the acceptability of a model for an individual case based on superior performance should be followed, as appropriate. Preparation and implementation of an evaluation protocol which is acceptable to both control agencies and regulated industry is an important element in such an evaluation."*

Regarding Section 3.2.2(b)(2), the improved performance of AERMOD with the ADJ_U* option compared to the default method was initially presented by EPA in their January 2014 AERMOD Modeling System Update Webinar (EPA 2014). During the webinar, EPA presented preliminary model performance evaluation results from a low wind-speed study at Oak Ridge, TN in complex terrain. The webinar also provided results from an evaluation of the Cordero Rojo surface coal mine study in Wyoming, examining monitored PM_{10} (particulate matter less than 10 microns in diameter) concentrations compared to modeled concentrations. A surface coal mine would have emission characteristics similar to those from the Donlin project. Both studies showed that AERMOD simulations using the ADJ_U* option demonstrate significantly improved correlation to field data compared to the default method (EPA 2014). Additionally in the webinar, EPA presented results from a model evaluation of the Idaho Falls tracer gas study for a low-level, non-buoyant release, which also showed that the use of ADJ_U* improved model performance.

In the June 2015 Addendum to the AERMOD User's Guide (EPA 2015b), EPA provided model evaluation results using AERMET/AERMOD version 15181 for the Oak Ridge and Idaho Falls tracer studies. Evaluation of the ADJ_U* option applied to these studies also showed improved model performance for version 15181, compared to the default method. Additionally, EPA performed an evaluation of ADJ_U* as applied to a tall stack (145 meters) in complex terrain for the Lovett Power Plant, New York study. Again, the ADJ_U* option improved model performance when compared to observations. Updated results from the Cordero Rojo surface coal mine study were not included in the AERMET/AERMOD version 15181 evaluation studies. However, per an EPA presentation at the 2015 Conference, EPA stated that it expected that the ADJ_U* evaluation results for that study "are likely to be similar for v15181" (EPA 2015d).

For these four studies, model performance improved significantly with the use of the ADJ_U* option compared to the default method. These studies are relevant to the proposed Donlin project due to similarities in terrain (complex) and emission characteristics (fugitive sources with low release heights or tall stacks, such as DGLLC's power plant stacks). Table 1 provides a summary of EPA's AERMET/AERMOD version 15181 ADJ_U* evaluation studies in the June 2015 Addendum to the AERMOD User's Guide (EPA 2015b) and the Cordero Rojo surface coal mine study presented in EPA's 2014 webinar.

DGLLC believes that the model evaluations performed by the EPA—presented in the 2014 webinar, and updated for AERMET/AERMOD version 15181 in the Users' Guide Addendums (EPA 2015a and 2015b)—sufficiently address the requirements of Section 3.2.2(d) for DGLLC's proposed use of the ADJ_U* option. Therefore, DGLLC seeks EPA and ADEC approval for application of the non-default ADJ_U* option in the AERMOD modeling for the Donlin project under Section 3.2.2(b)(2) of the Guideline.

3.3 Site-Specific Sigma Meteorological Data

On August 20, 2015, it was brought to DGLLC's attention by ADEC that EPA had recently expressed concern with the use of site-specific sigma meteorological data in conjunction with ADJ_U*. Therefore, DGLLC is open to an approval of the ADJ_U* option that may include conditions regarding the use of site-specific sigma meteorological data in conjunction with ADJ_U*.

Table 1. Summary of EPA's ADJ_U* Evaluations for AERMET/ AERMOD Version 15181

Study Name	Release Type	Terrain / Surroundings	Applicable to Donlin?	Model Performance Without ADJ_U*	Model Performance With ADJ_U*	Overall Conclusions
Oak Ridge	Low-level, non-buoyant release (1 m)	Complex terrain, Rural, Open-area	Yes - Donlin is located in complex terrain and has numerous, low-level fugitive emission sources	Model over-predicts observations by a factor of 2 to 30 (EPA 2015b, Pages F-6 and F-11)	Model agrees with observations within a factor of 1 to 2 (EPA 2015b, Pages F-8 and F-14)	"significant improvement in model performance with the ADJ_U* option in AERMET" (EPA 2015b, Page F-16).
Idaho Falls	Low-level, non-buoyant release (3 m)	Flat/even terrain, Open-area	Yes - Donlin has low-level, non-buoyant fugitive sources, but terrain is different	Model over-predicts observations by a factor of 2 (EPA 2015b, Pages F-6 and F-11)	Model agrees with observations within a factor of 1 to 2 (EPA 2015b, Pages F-25 and F-26)	Generally good model performance at receptors nearest the release. As noted by EPA, "For this type of source, i.e., a non-buoyant, ground-level or low-level source (e.g., fugitive emission), the maximum ambient impacts are likely to occur at the fenceline" (EPA 2015b, Page F-18). Relevant to DGLLC operations/modeling.
Lovett	Tall stack (145 m)	Complex terrain, Rural, Open-area	Yes - Donlin is located in complex terrain and has tall point sources such as the power plant stacks (49 m)	"Past evaluations of AERMOD have shown good performance" (EPA 2015b, Page F-33). The consideration of ADJ_U* reduces the model over-predictions slightly.		Model performance improvement when using ADJ_U* (EPA 2015b, Pages F-33 and F-34).
Cordero Rojo (Wyoming surface coal mine)	Surface mine; majority of emissions from haul roads	Flat/even terrain, Rural, Open-area	Yes - Donlin has low-level, non-buoyant fugitive sources, but terrain is different	EPA evaluated ADJ_U* for AERMOD version 14134, not for version 15181. "Use of the proposed ADJ_U* option in AERMET appears to significantly improve model performance for this study" (EPA 2015d).		Significant improvement in model performance when using ADJ_U*. The results for this study are "based on v14134, but are likely to be similar for v15181" (EPA 2015d).

4.0 References

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Paine, B. and J. Connors. 2013. "AERMOD Low Wind Speed Issues: Review of New Model Release." AECOM. EPA 2013 Modeling Workshop Presentation. April 23, 2013. Accessed August 24, 2015. http://www.cleanairinfo.com/regionalstatelocalmodelingworkshop/archive/2013/Files/Presentations/Tuesday/105-Review_of_AERMOD_Low_Wind_Speed_Options_Paine.pdf.

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Attachment C: DGLLC 2 September 2015 Letter

September 2, 2015

Mr. Alan Schuler
Division of Air Quality
Alaska Department of Environmental Conservation (ADEC)
410 Willoughby Avenue, Suite 303
PO Box 111800
Juneau, AK 99811-1800

RE: Responses to EPA R10 Comments on DGLLC's ADJ_U* Approval Request

Dear Mr. Schuler,

This letter provides responses to comments from the U.S. Environmental Protection Agency (EPA) Region 10 (R10) email dated August 27, 2015, regarding the Donlin Gold LLC (DGLLC) request to use a non-default adjusted surface friction velocity (ADJ_U*) option in the AERMOD modeling for the proposed Donlin project in southwestern Alaska.

Each comment from EPA R10 (except for Comment 1, which requires a response from ADEC) is reiterated herein, followed by a DGLLC response.

EPA R10's Comments 2-5 and DGLLC's Responses

Comment 2.
Figure 1 plots Option 1 and default u_*. The total hours do not total five years. Are those American Ridge hours missing and/or bad data?

Response to Comment 2.
The friction velocity (u*) frequency chart provided in Figure 1 was based on five years (July 1, 2005 – June 30, 2010) of American Ridge meteorological data. This data period consists of a total of 43,824 hours (including a leap year). There is a total of 41,318 hourly u* values provided in Figure 1 for each option (default and ADJ_U*). There are 2,506 hours in this data set for which AERMET did not calculate u* due to missing/calm winds or other missing parameters.

Comment 3.
AERMOD and AERMET input files should be provided for us to review and accept, and made part of the public record.

Response to Comment 3.
Electronic AERMOD and AERMET input and output files will be provided via the DGLLC ftp site (https://ftp.donlingold.com). User name, password and folder information will be provided by e-mail.

Comment 4.
Figure 2 – Figure 7 shows 24-hour average friction velocity vs 24-hour concentrations for six source groups.

a. *Explain 24-hour emissions.*

b. *Is each filled in circle or triangle representative of a day in the year?*

c. *R10 suggest that Donlin provide a similar plot of the haul roads but for default u*, Adj_u*, 0 < L < 50 m, and wind direction (+/-5 degrees) from the haul roads to the receptor.*

Response to Comment 4.

a. Table A provides the modeled emissions rates in grams per second (g/s) for the six source groups (listed in Table 1) that were used to estimate the 24-hour concentrations presented in Figures 2 through 7.

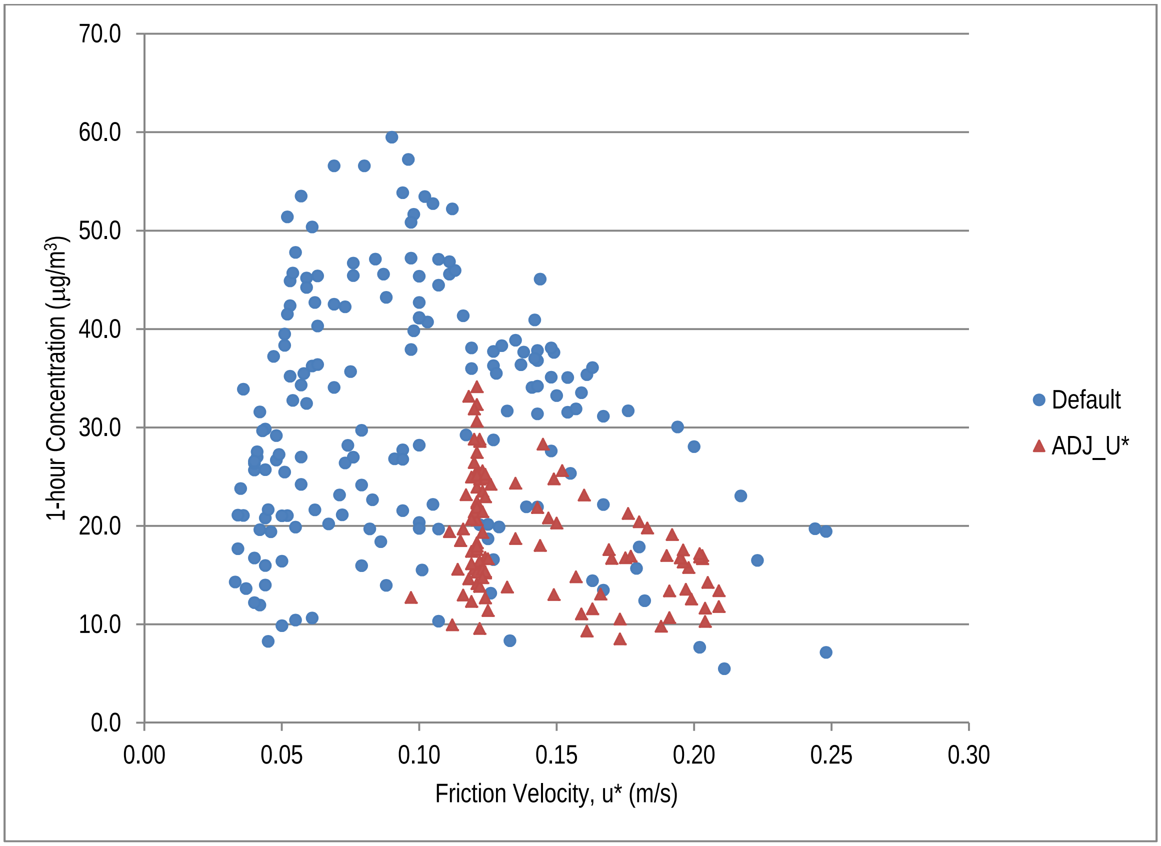
Table A. Modeled Emission Rates

Source Group Description	Modeled Emissions (g/s)
Process and Ancillary Sources, Excluding Power Plant	3.153
Power Plant	8.393
All Haul Roads	19.240
Blasting	5.809
In-pit, Excluding Hauling and Blasting	8.403
Waste Rock Storage	8.525

b. Confirmed, each blue circle and red triangle represents a 24-hour modeled concentration for the default and ADJ_U* options, respectively.

c. The requested hourly concentration plot for the haul road source group is provided in Figure A. This plot presents the hourly modeled concentrations for both the default and ADJ_U* options, as a function of hourly u* values. This plot only includes hours when winds are blowing within a 10-degree sector (+/- 5 degrees) from the haul road network toward the modeled receptor, and the Monin-Obukhov Length (L) values are between 0 to 50 meters (m).

Figure A. 10-Degree Sector Winds, 0 < L < 50 m: Concentrations vs. u* Values – Source Group: Haul Roads



Comment 5.
In the Technical Memorandum,

a. *Page 4, second paragraph, what is reference for the phrase "frequent cloudy conditions"?*

b. *Page 4, second paragraph, what is the period of record for the meteorology which I assume is American Ridge?*

c. *Page 6, Section 3.2, second full paragraph. Reference is made to the Oak Ridge, TN, Cordero Rojo surface mine in Wyoming, Idaho Falls, and Lovett Power Plant, New York studies. These four references should be included as an appendix if they apply directly to this request.*

Response to Comment 5.

a. The term "frequent cloudy conditions" is used to describe generally occurring cloud conditions in the region where the Donlin project is located. A review of Sleetmute National Weather Service station historical (2006 – 2012) records[1] shows that partly cloudy to overcast conditions existed 95 percent of the time.

b. The period of record is July 1, 2005 – June 30, 2010 for the American Ridge meteorological data set.

c. The cited evaluation studies (excerpts from EPA 2015a and EPA 2015d) are provided in Appendix A to this letter.

Please contact me should you have any questions or require additional information.

Sincerely,

Michael Rieser
Senior Environmental Engineer

Attachments:
Appendix A – ADJ_U* Evaluation Studies

cc by e-mail:
Patrick Dunn, Division of Air Quality, ADEC
James Renovatio, Division of Air Quality, ADEC
Robert (Nick) Enos, DGLLC

[1] https://weatherspark.com/averages/33057/Sleetmute-Alaska-United-States. Accessed August 28, 2015.

Appendix A – ADJ_U* Evaluation Studies

ADDENDUM

USER'S GUIDE FOR THE AMS/EPA REGULATORY MODEL - AERMOD (EPA-454/B-03-001, September 2004)

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air Quality Planning and Standards
Air Quality Assessment Division
Research Triangle Park, North Carolina 27711

June 2015

APPENDIX F. EVALUATION OF LOW WIND BETA OPTIONS

Beginning with version 12345, AERMOD includes non-default BETA options to address concerns regarding model performance under low wind speed conditions. This included the LOWWIND1 and LOWWIND2 BETA options on the MODELOPT keyword in AERMOD, and the ADJ_U* option included in Stage 3 of the AERMET meteorological processor. Beginning with version 15181 a new LOWWIND3 BETA option was incorporated into AERMOD. The LOWWIND3 option increases the minimum value of sigma-v from 0.2 to 0.3 m/s, consistent with the LowWind2 option, but eliminates upwind dispersion, consistent with the LowWind1 option. The LowWind3 option uses an "effective" sigma-y value that replicates the centerline concentration accounting for meander, but sets concentrations to zero (0) for receptors that are more than 6*sigma-y off the plume centerline, similar to the FASTALL option.

Updated evaluation results for these BETA options based on version 15181 of AERMOD are presented below for two field studies conducted in 1974 by the Air Resources Laboratory of the National Oceanic and Atmospheric Administration (NOAA) to investigate diffusion under low wind speed conditions at Idaho Falls (NOAA, 1974) and Oak Ridge (NOAA, 1976). These two field studies were used in the API-sponsored evaluations of AERMOD conducted by AECOM (AECOM, 2009), that were subsequently submitted as part of API's public comments on EPA's 10^{th} Conference on Air Quality Models held in March 2012. Each of these studies used tracer releases with three arcs of samplers located at 100m, 200m, and 400m from the release point. Diagrams for each of the study areas are presented below.

In addition, since the ADJ_U* option in AERMET and the LowWind option in AERMOD are focused on improving model performance during periods of stable/low-wind conditions, additional evaluations are presented below for the Lovett evaluation database, a tall stack located in complex terrain where stable/low-wind conditions can also be important.

The evaluation results presented here for the Idaho Falls and Oak Ridge studies were based in part on the information included in the AECOMs 2009 report and data files subsequently provided by AECOM. However, some adjustments to inputs were made based on an independent assessment of the surface roughness for each of the study locations, an adjustment to the effective tracer release height at Idaho Falls from 1.5 to 3m based on information provided on page 24 of the NOAA Technical Memorandum for Idaho Falls (NOAA, 1974), and adjustments to the wind measurement height for Oak Ridge based on the discussion in Section 2.2 and information provided in Table 1 of the NOAA Technical Memorandum for Oak Ridge (NOAA, 1976).

The AECOM evaluation for Oak Ridge assumed a 2m wind measurement height, whereas page 8 of the NOAA report for Oak Ridge indicated that the wind measurements were "accomplished by laser anemometry" because wind speeds were "below the threshold of standard cup anemometers." Footnotes in Table 1 also confirm that wind speeds were "measured by laser anemometers" for all tests, except for Test 11 where the wind speed was measured at the 30.5m level on one of meteorological towers included in the study. Given that the transmitters and receivers for the laser anemometer were located on the hills on either side of the valley where the tracer was released, at elevations between 50 to 100 feet higher than the elevation at the release point (based on Figure 2b of the NOAA report), a 2m wind measurement height may not be appropriate. However, the NOAA report does not indicate an "effective" measurement height above ground for the wind speeds measured by the laser anemometers. Another aspect of the use of laser anemometry that complicates the determination of an appropriate measurement height is that the "measured" wind speeds may represent more of a volume average than a point measurement. Since the wind speeds estimated by laser anemometry are likely to be more representative of vector averaged wind speeds than scalar averages the VECTORWS option in AERMOD was used for the Oak Ridge evaluations.

Based on these considerations, the evaluation results presented here were based on an "effective" wind measurement height of 10m, and the winds were also assumed to represent vector mean wind speeds. In addition to the different assumptions regarding the appropriate measurement height to assign to the observed wind speeds at Oak Ridge, the results presented below are based on a surface roughness length of 0.6m, consistent with the forest covering most of the study area at the time. The AECOM study assumed a much smaller roughness length of 0.2m.

A series of figures is provided below for each site, starting with the Oak Ridge study followed by the Idaho Falls study. For each site a series of Q-Q plots (results paired by rank), plots of concentrations paired in time, and residual plots showing the distribution of predicted/observed concentration ratios versus downwind distance are provided. Results are shown for the following scenarios:

- Current regulatory default options, i.e., no adjustments (No ADJ_U*/No LowWind)
- U* adjustment with no low wind options (ADJ_U*/No_LowWind)
- U* adjustment with LOWWIND1 (ADJ_U*/LowWind1)
- U* adjustment with LOWWIND2 (ADJ_U*/LowWind2)
- U* adjustment with LOWWIND3 (ADJ_U*/LowWind3)

Based on the limited meteorological data available for the Oak Ridge study, a single set of model comparisons is presented. Given the more robust meteorological data available from the Idaho Falls study, including multiple levels of wind speed, direction, temperature, and sigma-theta, several sets of meteorological inputs are evaluated, including the use of delta-T data with the Bulk Richardson Number (BULKRN) option available in AERMET.

Another important difference between these two field studies is that the Oak Ridge site was located in a hilly area on the Oak Ridge peninsula, with terrain elevations varying about 40m across the study area, with the tracer release point located near the center of the valley that cuts across the peninsula. Given the very low wind speeds during the study period, drainage flows and valley channeling may have influenced plume dispersion. The influence of terrain on low-level non-buoyant releases in AERMOD has not been assessed, and neither the AECOM nor EPA results for Oak Ridge have incorporated terrain elevations in their respective evaluations. As a result, the evaluations based on the Idaho Falls are likely to be more robust than the evaluations based on Oak Ridge.

As noted above, the Oak Ridge evaluations are based on a single set of meteorological inputs, whereas the Idaho Falls evaluation are based on a range of options given the more robust data available. These various sets of meteorological inputs for Idaho Falls are referred to in the figure captions as follows:

1. Base 1-level: no delta-T or turbulence (i.e., sigma-theta) data included;

2. Full 1-level: no delta-T data with sigma-theta data;
3. Base 2-level: delta-T data used with BULKRN option without sigma-theta;
4. Full 2-level: delta-T data used with BULKRN option with sigma-theta

Each of these data sets were used with and without the ADJ_U* option in AERMET and also with and without the LowWind options. For purposes of assessing the proposed BETA options, including the ADJ_U* option in AERMET and the LowWind options in AERMOD, the comparisons below are limited to the current default options, i.e., without ADJ_U* and without the LowWind option (labeled as NoADJ and NoLW), and the proposed options of ADJ_U* and LowWind3 (labeled as ADJ and LW3).

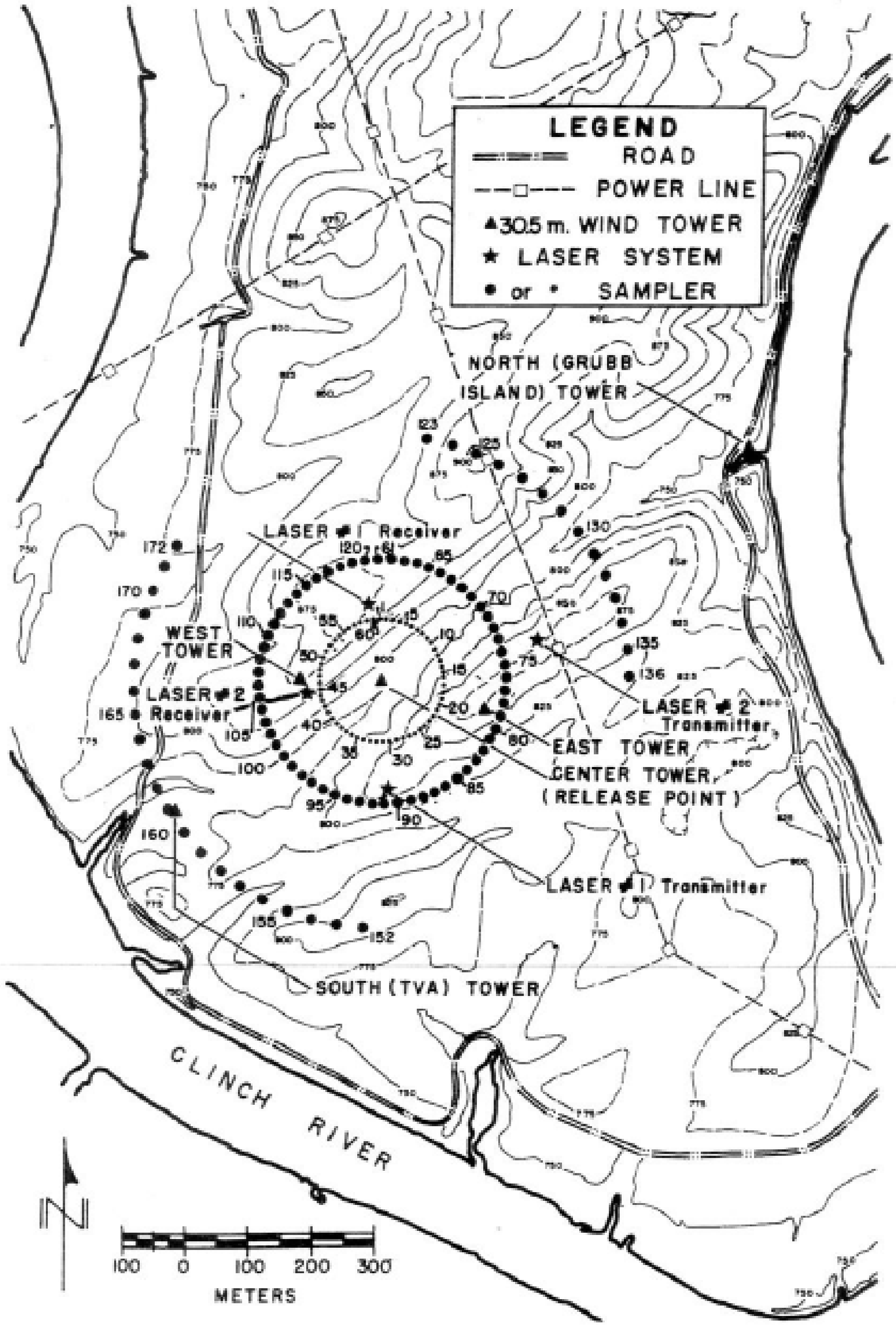
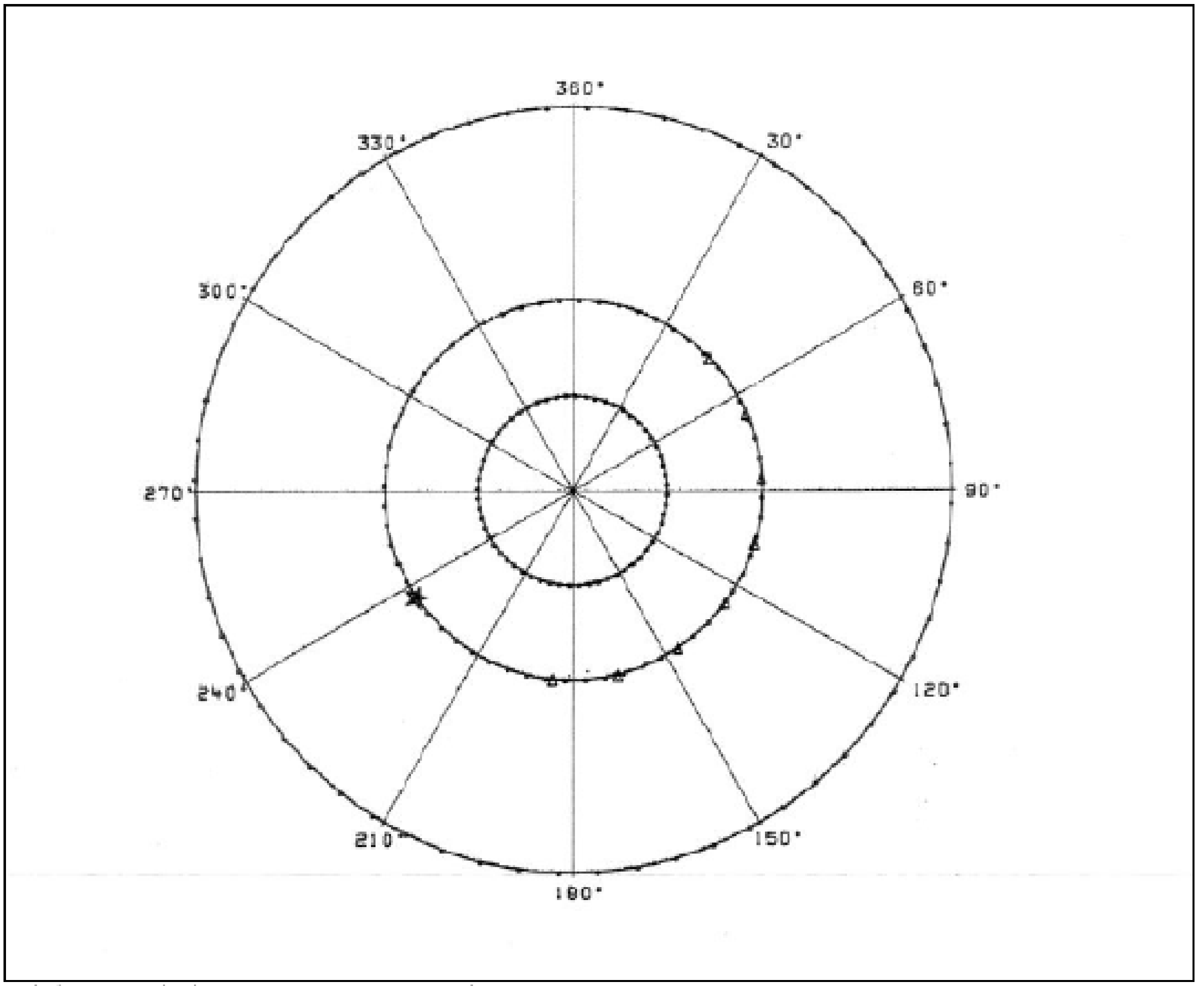


Figure 2b. Detail of inner sampling arcs showing location of meteorological towers and laser transmitters and receivers. (Contour heights are in feet above sea level).

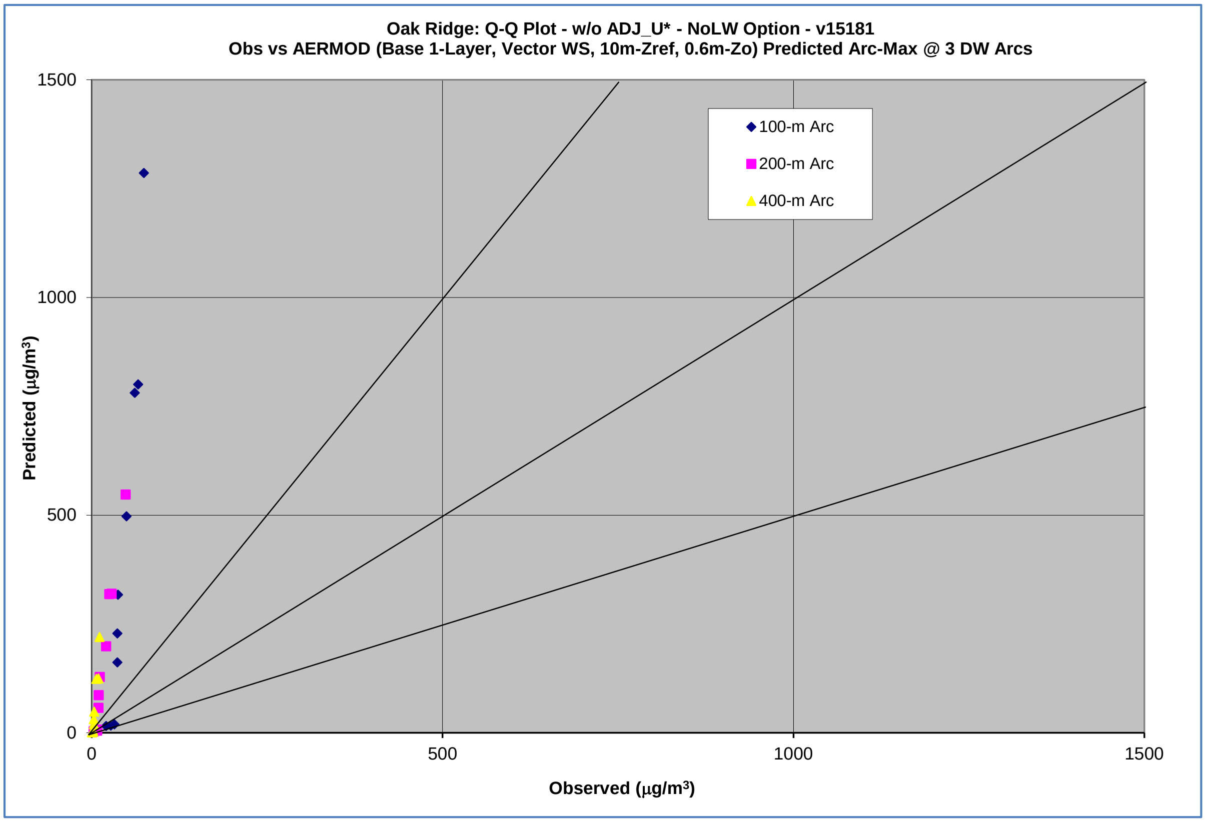
Figure 9-4: Depiction of Sampler Array for Idaho Falls



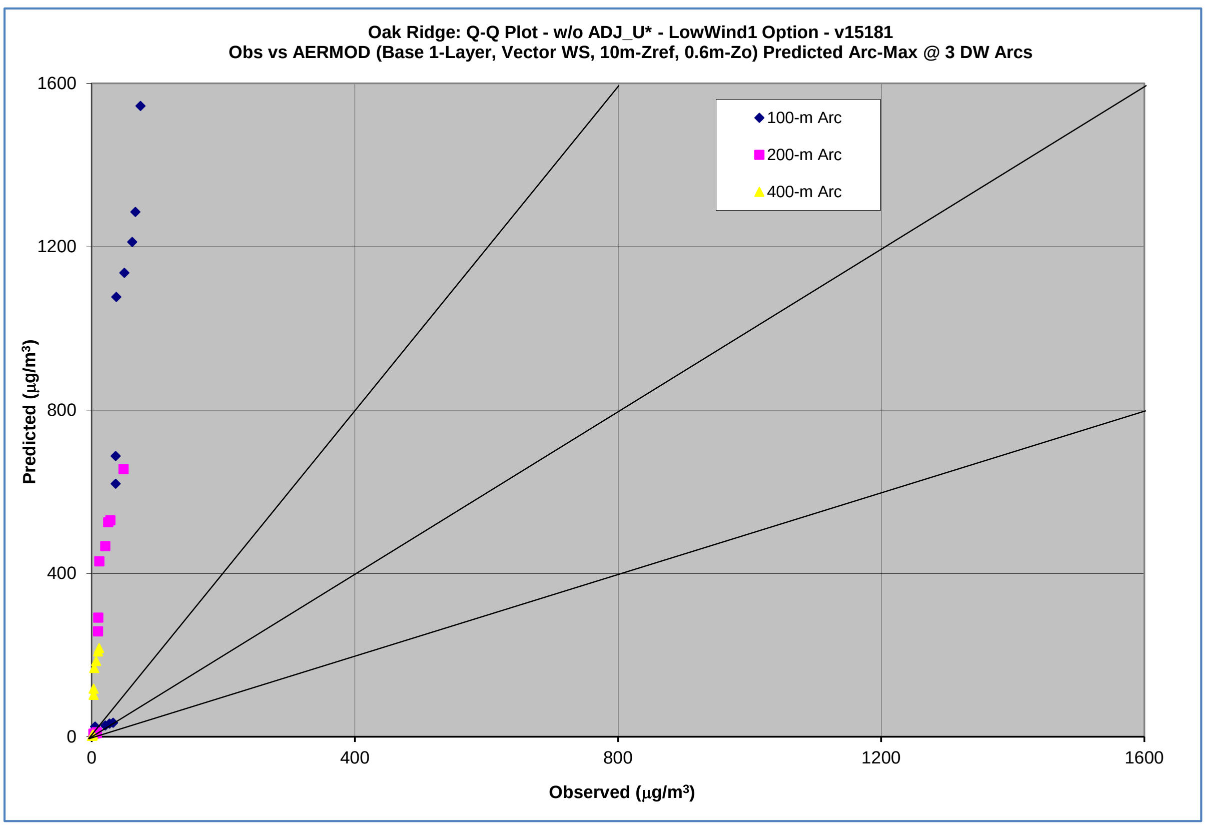
Note: the arcs are at distances of 100, 200, and 400 m from the source.

A series of figures is provided below for each site, starting with the Oak Ridge study followed by the Idaho Falls study. For each site, a series of **Q-Q plots** (i.e., results paired by rank and arc distance), **paired plots** (i.e., results paired in time and arc distance), and **residual plots** (showing the distribution of Pred/Obs ratios by distance) are shown in the following order:

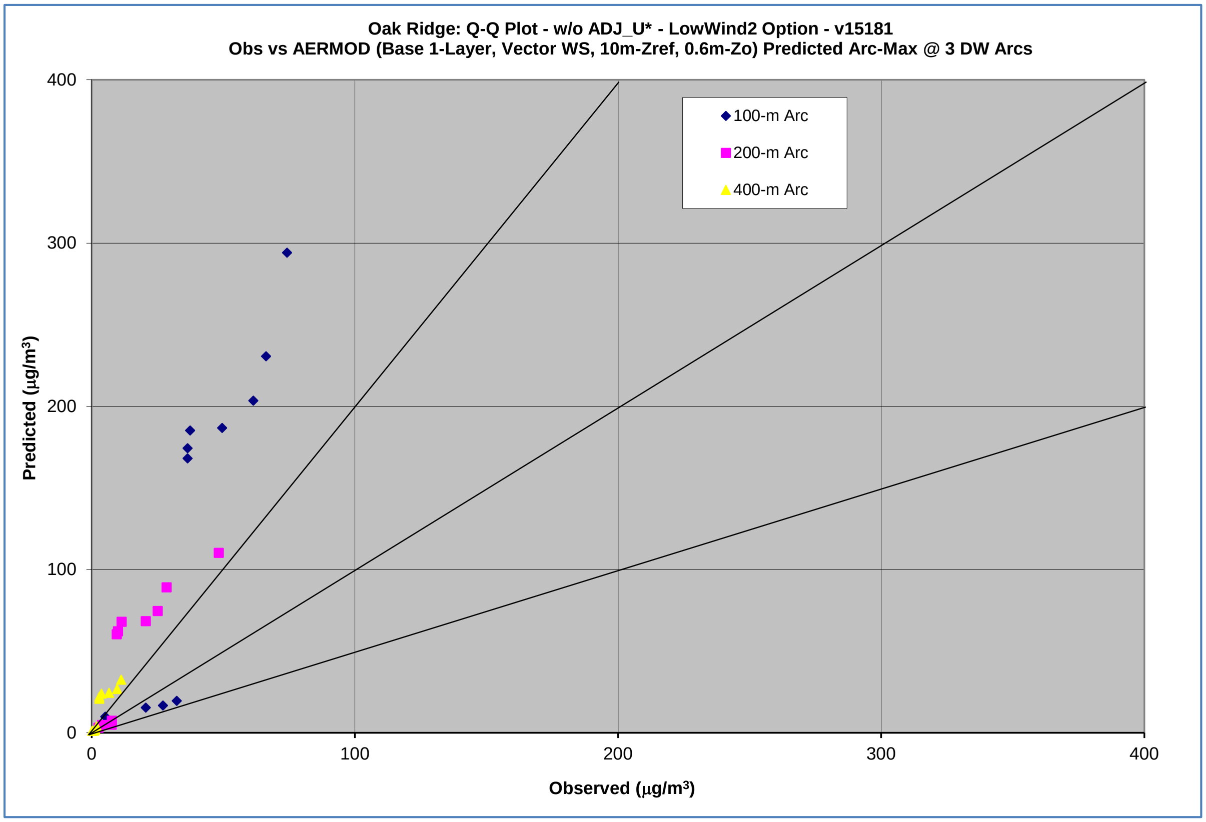
No ADJ_U* / No LowWind Option;
No ADJ_U* / LowWind1 Option;
No ADJ_U* / LowWind2 Option;
No ADJ_U* / LowWind3 Option;
ADJ_U* / No LowWind Option;
ADJ_U* / LowWind1 Option;
ADJ_U* / LowWind2 Option; and
ADJ_U* / LowWind3 Option.

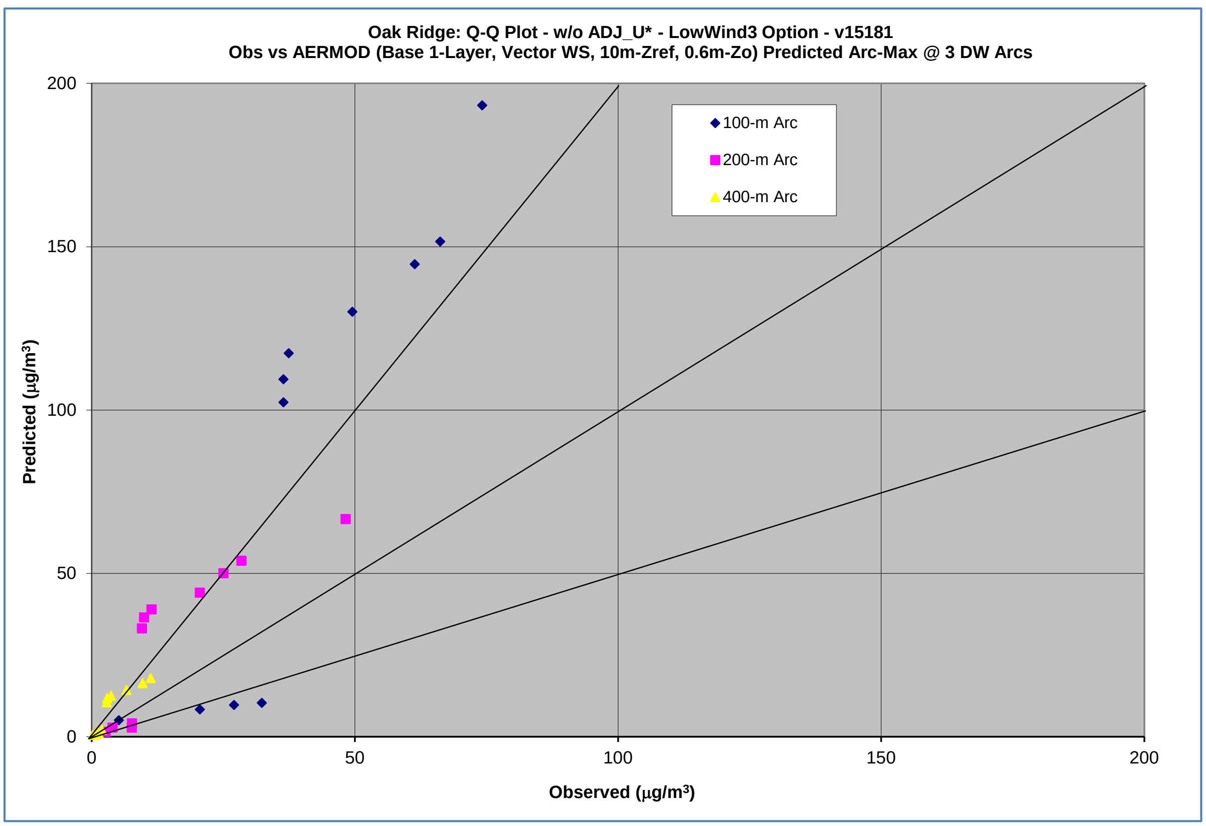


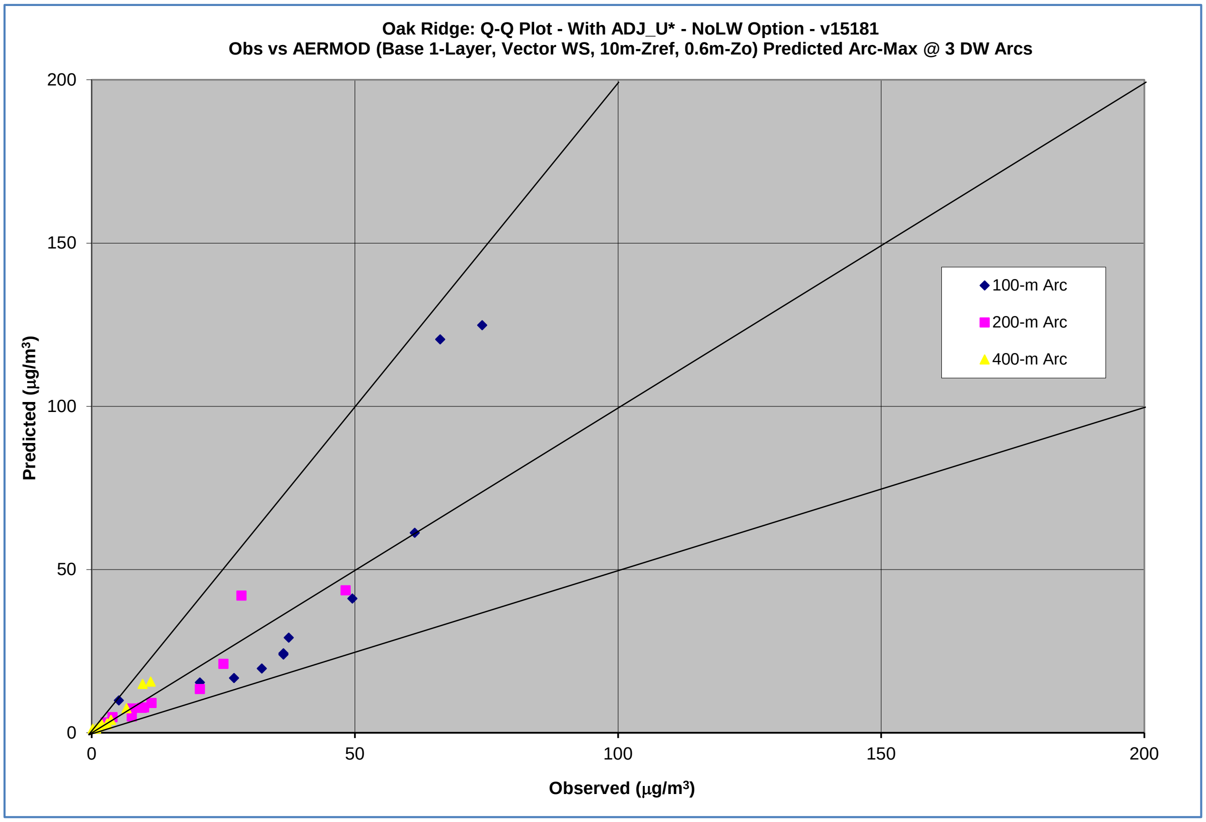
Oak Ridge: Q-Q Plot - w/o ADJ_U* - NoLW Option - v15181
Obs vs AERMOD (Base 1-Layer, Vector WS, 10m-Zref, 0.6m-Zo) Predicted Arc-Max @ 3 DW Arcs
1500
1000
500
0
0
500
1000
1500
Predicted (µg/m³)
Observed (µg/m³)
100-m Arc
200-m Arc
400-m Arc

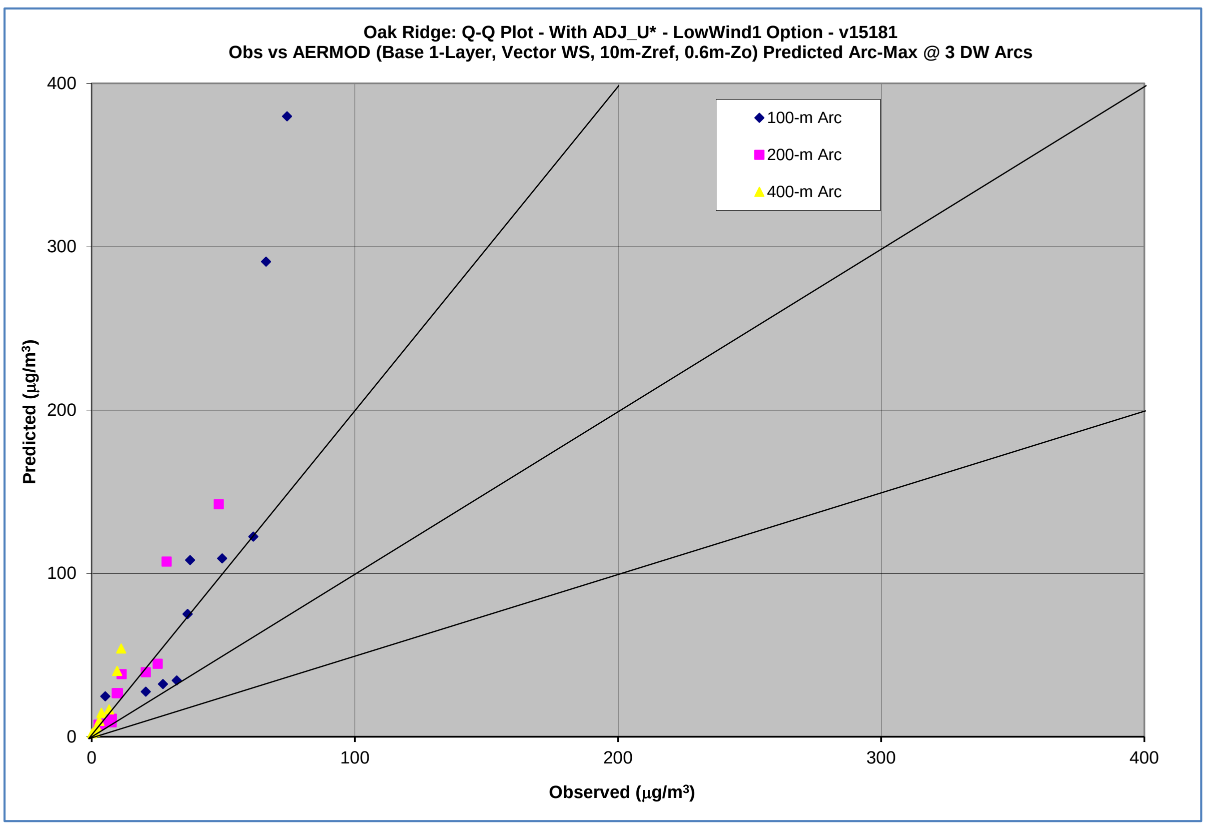


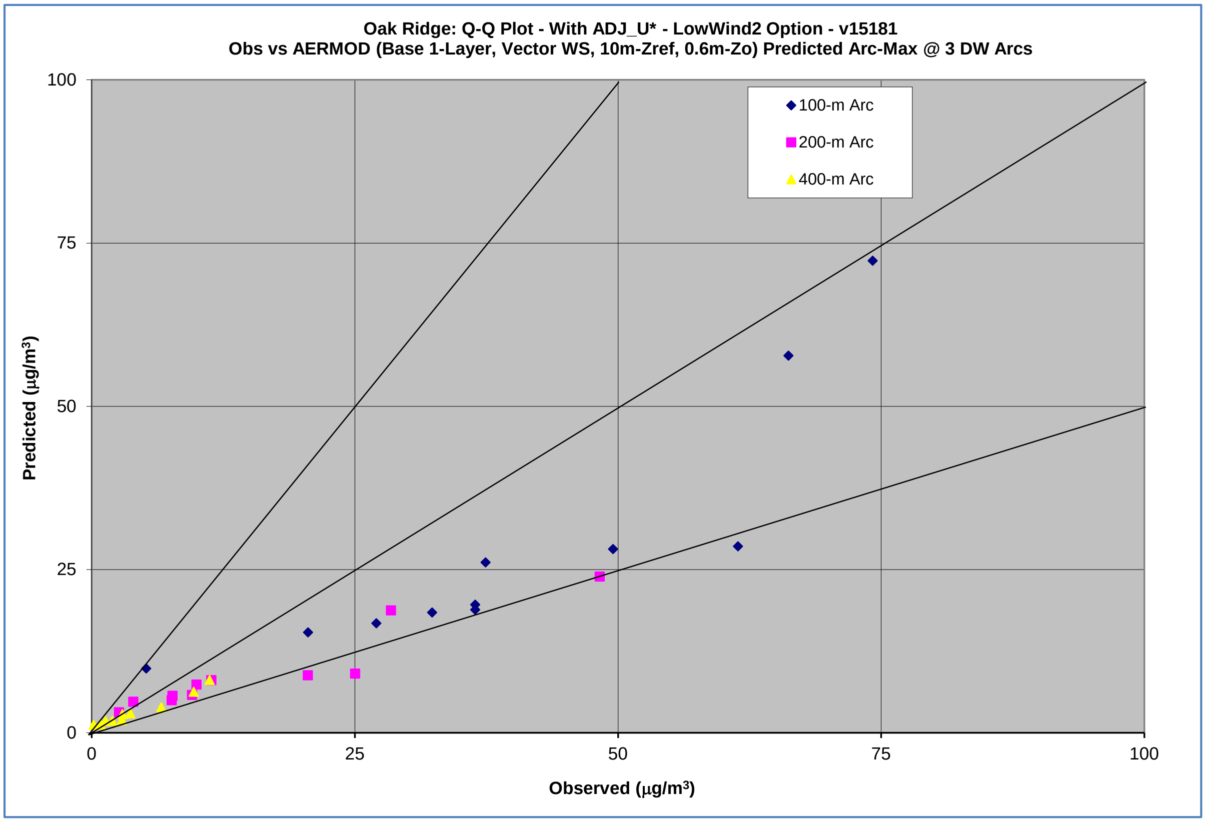
Oak Ridge: Q-Q Plot - w/o ADJ_U* - LowWind1 Option - v15181
Obs vs AERMOD (Base 1-Layer, Vector WS, 10m-Zref, 0.6m-Zo) Predicted Arc-Max @ 3 DW Arcs
1600
1200
800
400
0
0
400
800
1200
1600
Predicted (µg/m³)
Observed (µg/m³)
100-m Arc
200-m Arc
400-m Arc

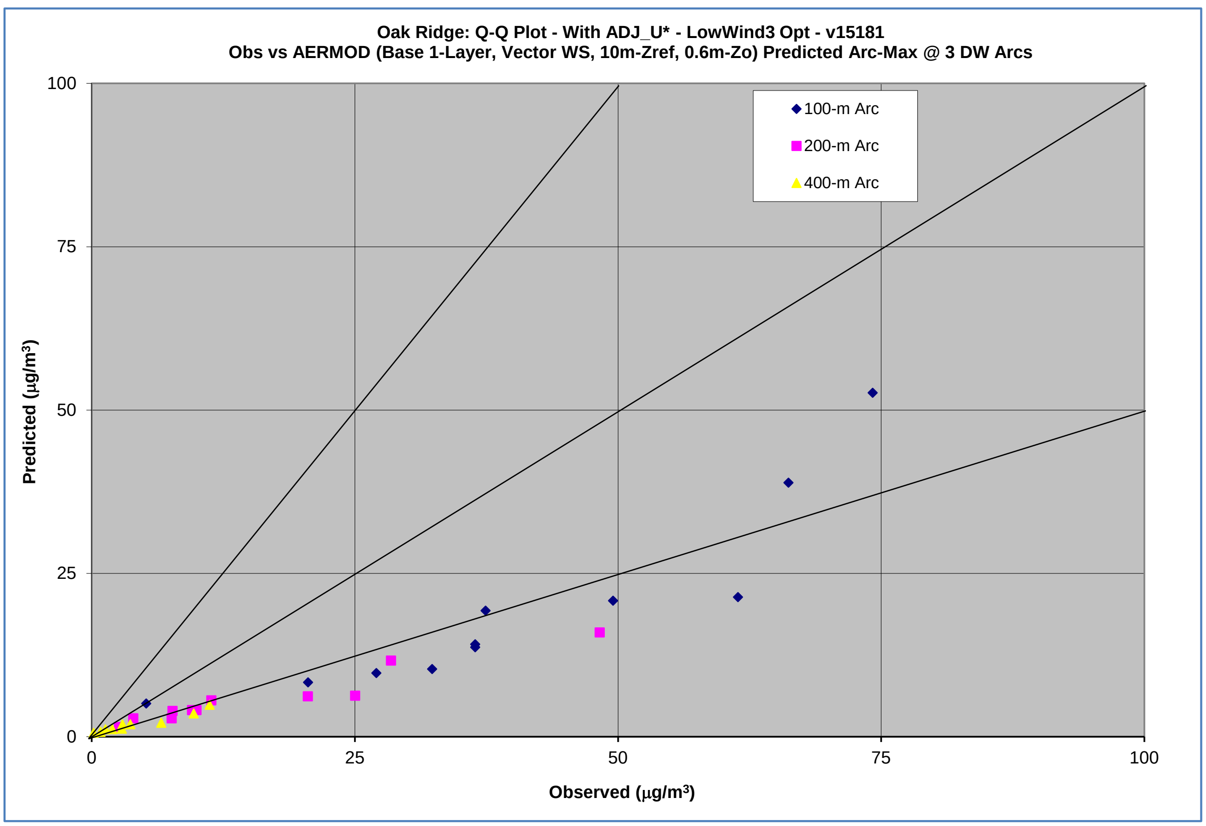

Oak Ridge: Q-Q Plot - w/o ADJ_U* - LowWind2 Option - v15181
Obs vs AERMOD (Base 1-Layer, Vector WS, 10m-Zref, 0.6m-Zo) Predicted Arc-Max @ 3 DW Arcs
100-m Arc
200-m Arc
400-m Arc
Predicted (µg/m³)
Observed (µg/m³)
0
100
200
300
400

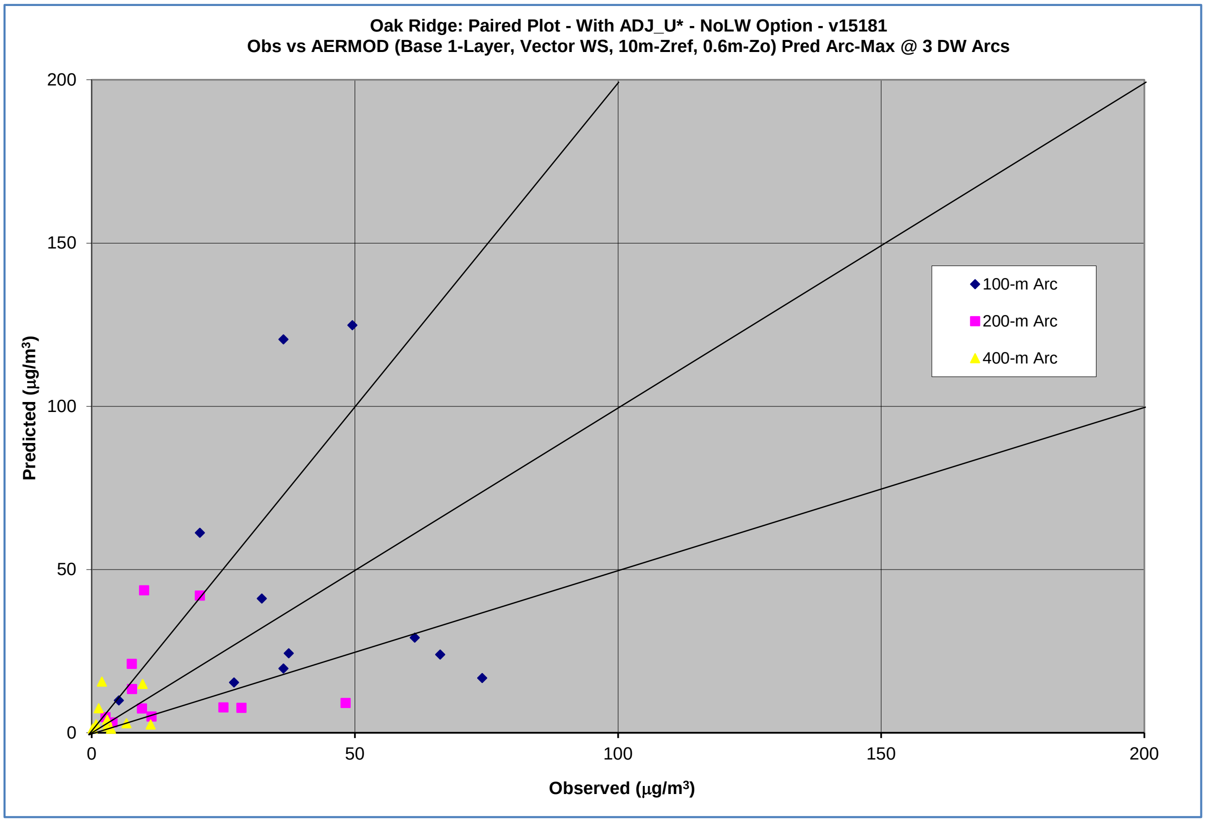

Oak Ridge: Q-Q Plot - w/o ADJ_U* - LowWind3 Option - v15181
Obs vs AERMOD (Base 1-Layer, Vector WS, 10m-Zref, 0.6m-Zo) Predicted Arc-Max @ 3 DW Arcs
100-m Arc
200-m Arc
400-m Arc
Predicted (µg/m³)
Observed (µg/m³)
0
50
100
150
200

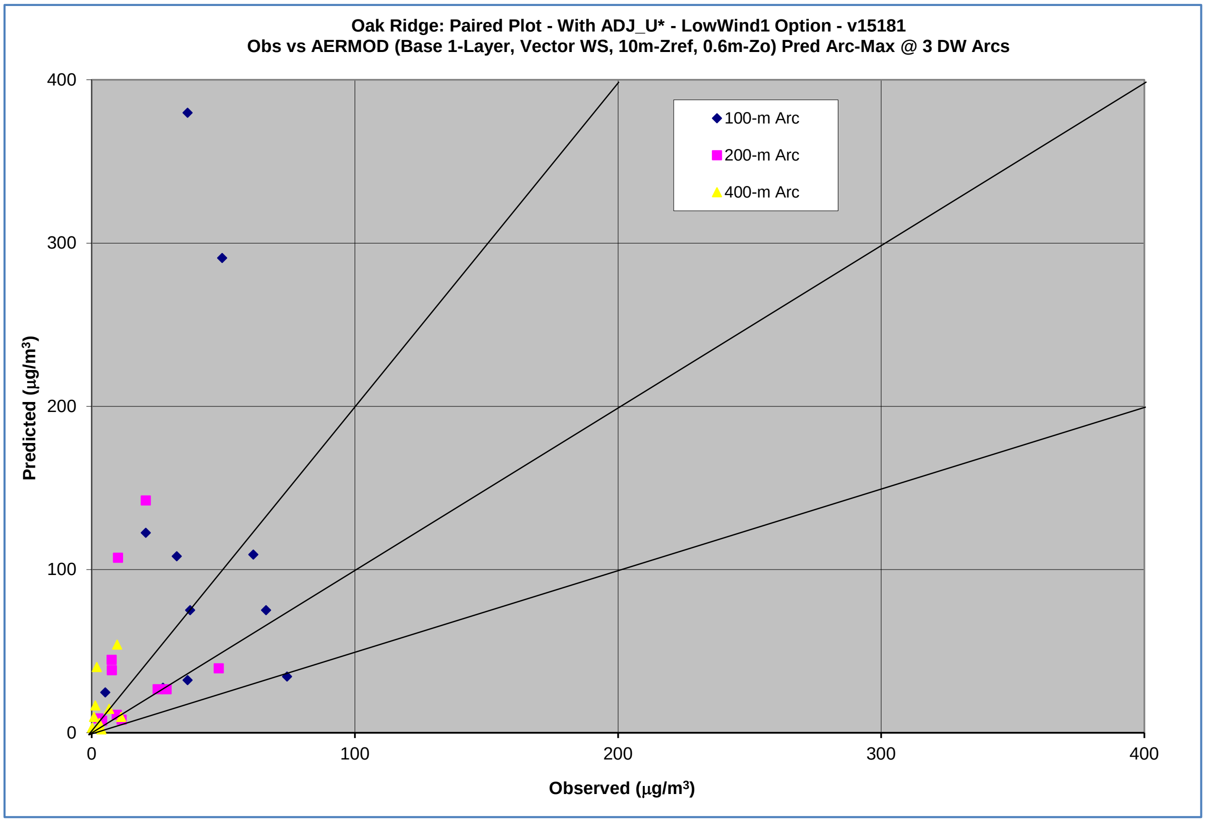

Oak Ridge: Q-Q Plot - With ADJ_U* - NoLW Option - v15181
Obs vs AERMOD (Base 1-Layer, Vector WS, 10m-Zref, 0.6m-Zo) Predicted Arc-Max @ 3 DW Arcs
Predicted (µg/m³)
Observed (µg/m³)
100-m Arc
200-m Arc
400-m Arc
0
50
100
150
200

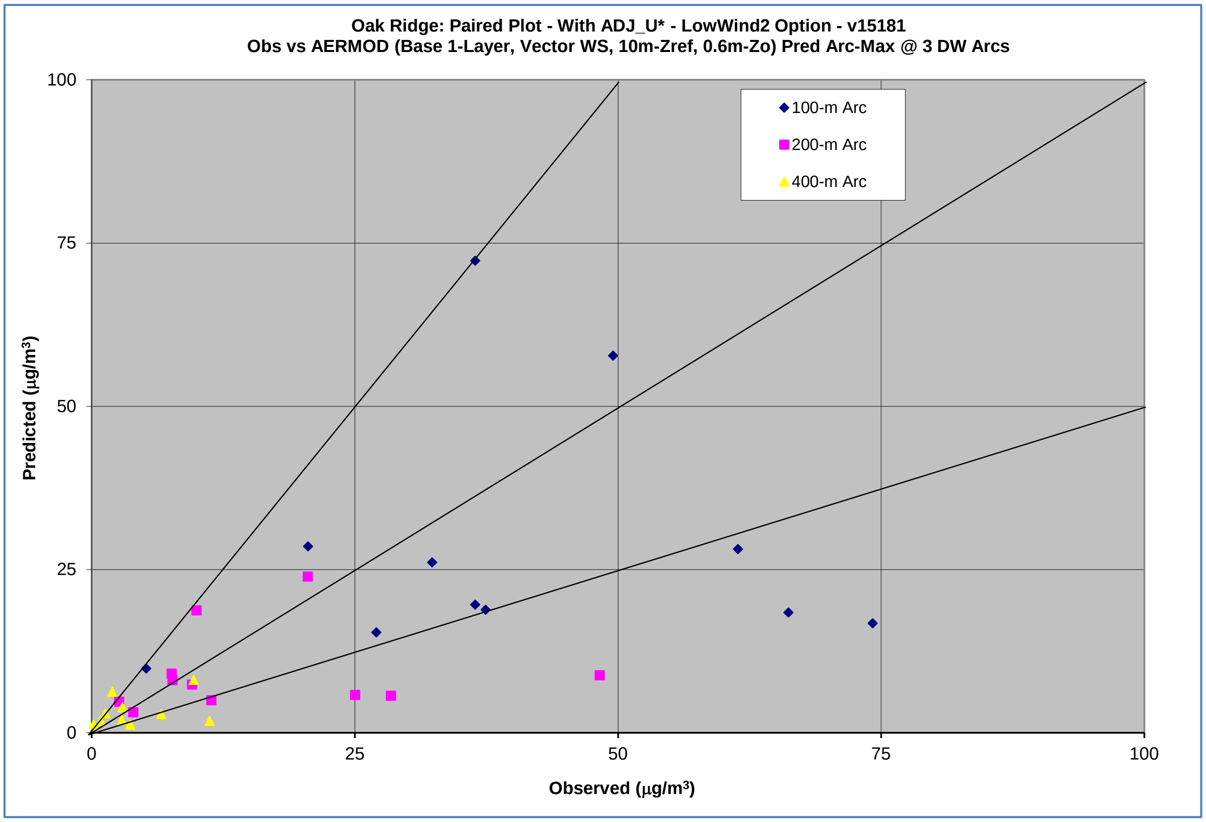

Oak Ridge: Q-Q Plot - With ADJ_U* - LowWind1 Option - v15181
Obs vs AERMOD (Base 1-Layer, Vector WS, 10m-Zref, 0.6m-Zo) Predicted Arc-Max @ 3 DW Arcs
Predicted (µg/m³)
Observed (µg/m³)
100-m Arc
200-m Arc
400-m Arc
0
100
200
300
400


Oak Ridge: Q-Q Plot - With ADJ_U* - LowWind2 Option - v15181
Obs vs AERMOD (Base 1-Layer, Vector WS, 10m-Zref, 0.6m-Zo) Predicted Arc-Max @ 3 DW Arcs
100-m Arc
200-m Arc
400-m Arc
Predicted (μg/m³)
Observed (μg/m³)
0
25
50
75
100

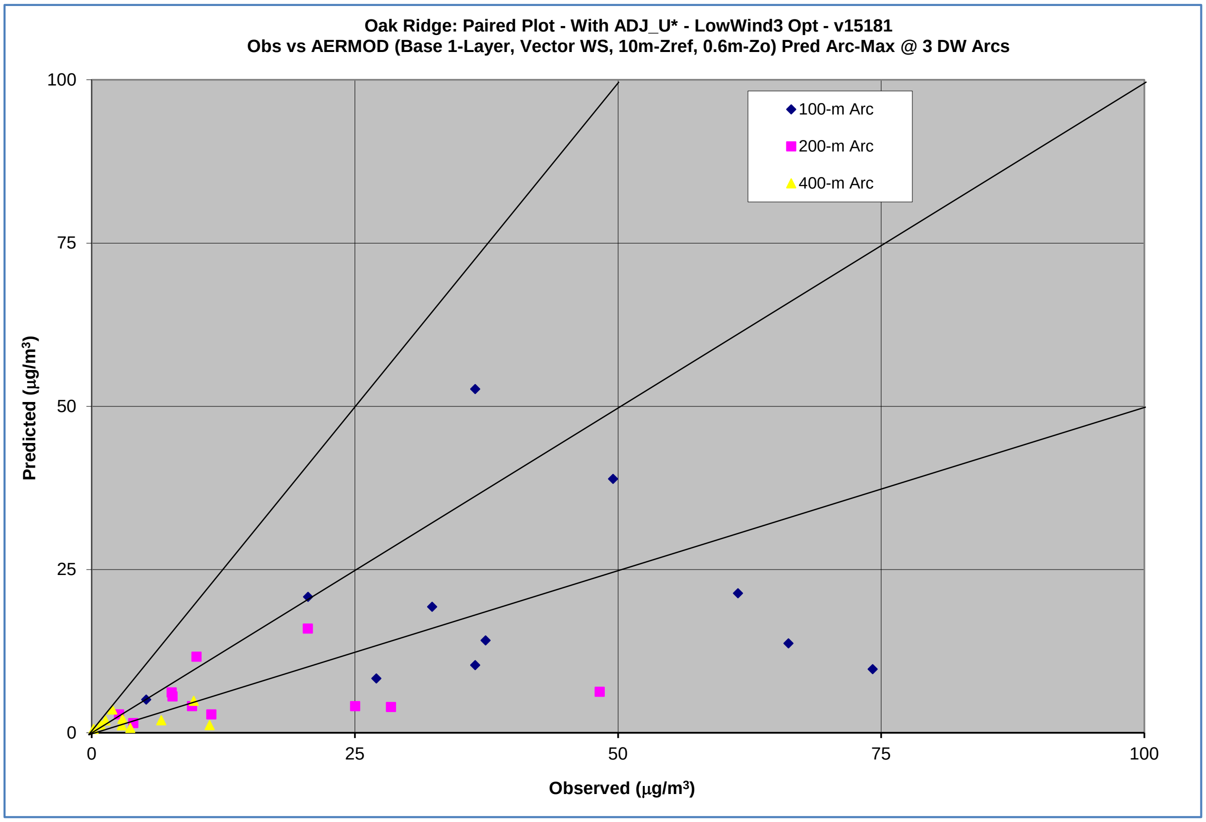

Oak Ridge: Q-Q Plot - With ADJ_U* - LowWind3 Opt - v15181
Obs vs AERMOD (Base 1-Layer, Vector WS, 10m-Zref, 0.6m-Zo) Predicted Arc-Max @ 3 DW Arcs
100-m Arc
200-m Arc
400-m Arc
Predicted (μg/m³)
Observed (μg/m³)
0
25
50
75
100


Oak Ridge: Paired Plot - With ADJ_U* - NoLW Option - v15181
Obs vs AERMOD (Base 1-Layer, Vector WS, 10m-Zref, 0.6m-Zo) Pred Arc-Max @ 3 DW Arcs
Predicted (μg/m³)
Observed (μg/m³)
100-m Arc
200-m Arc
400-m Arc
0
50
100
150
200

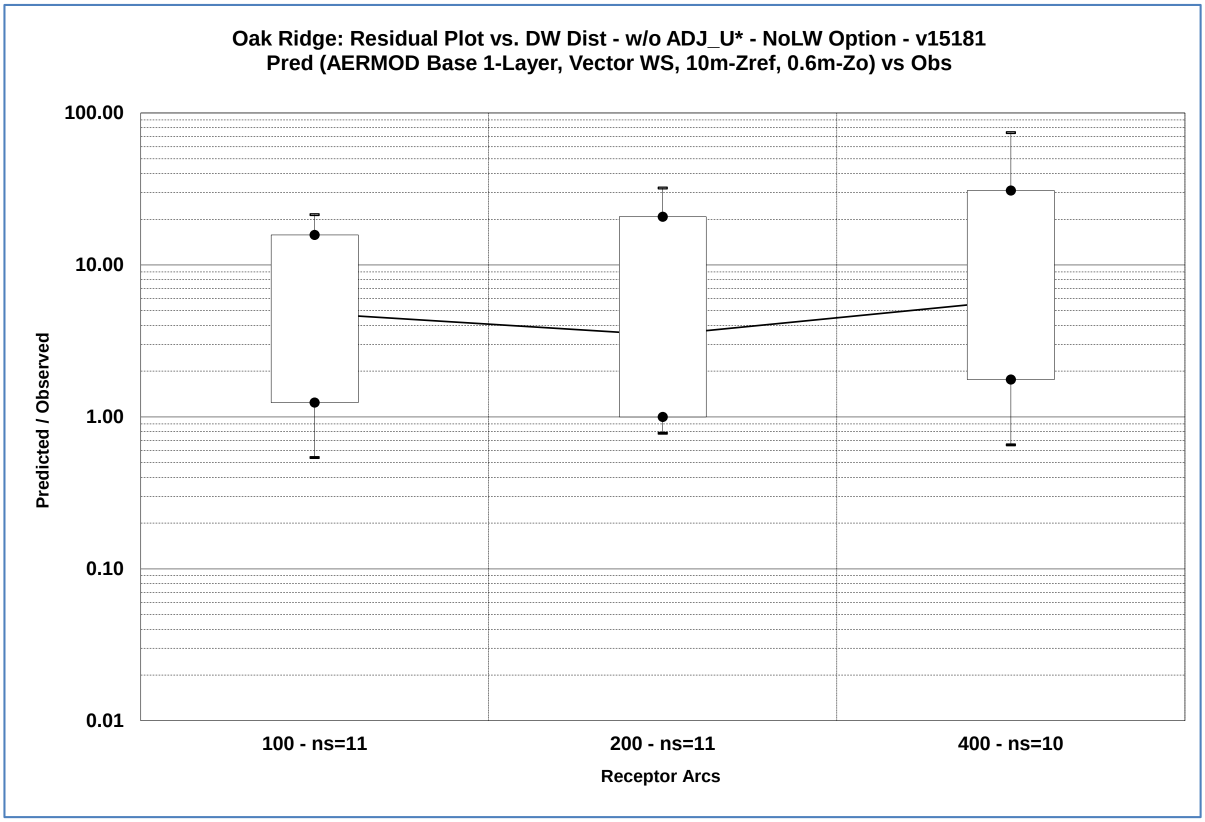

Oak Ridge: Paired Plot - With ADJ_U* - LowWind1 Option - v15181
Obs vs AERMOD (Base 1-Layer, Vector WS, 10m-Zref, 0.6m-Zo) Pred Arc-Max @ 3 DW Arcs
Predicted (μg/m³)
Observed (μg/m³)
100-m Arc
200-m Arc
400-m Arc
0
100
200
300
400

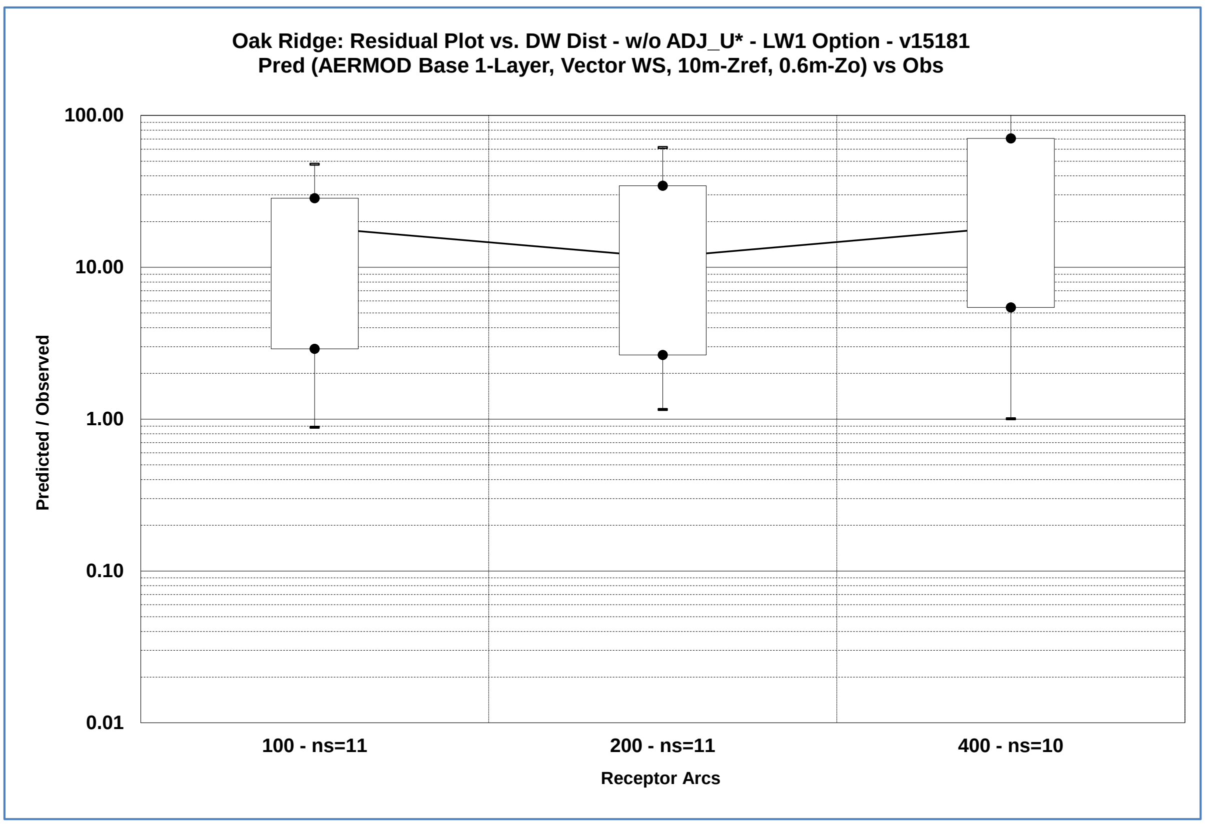


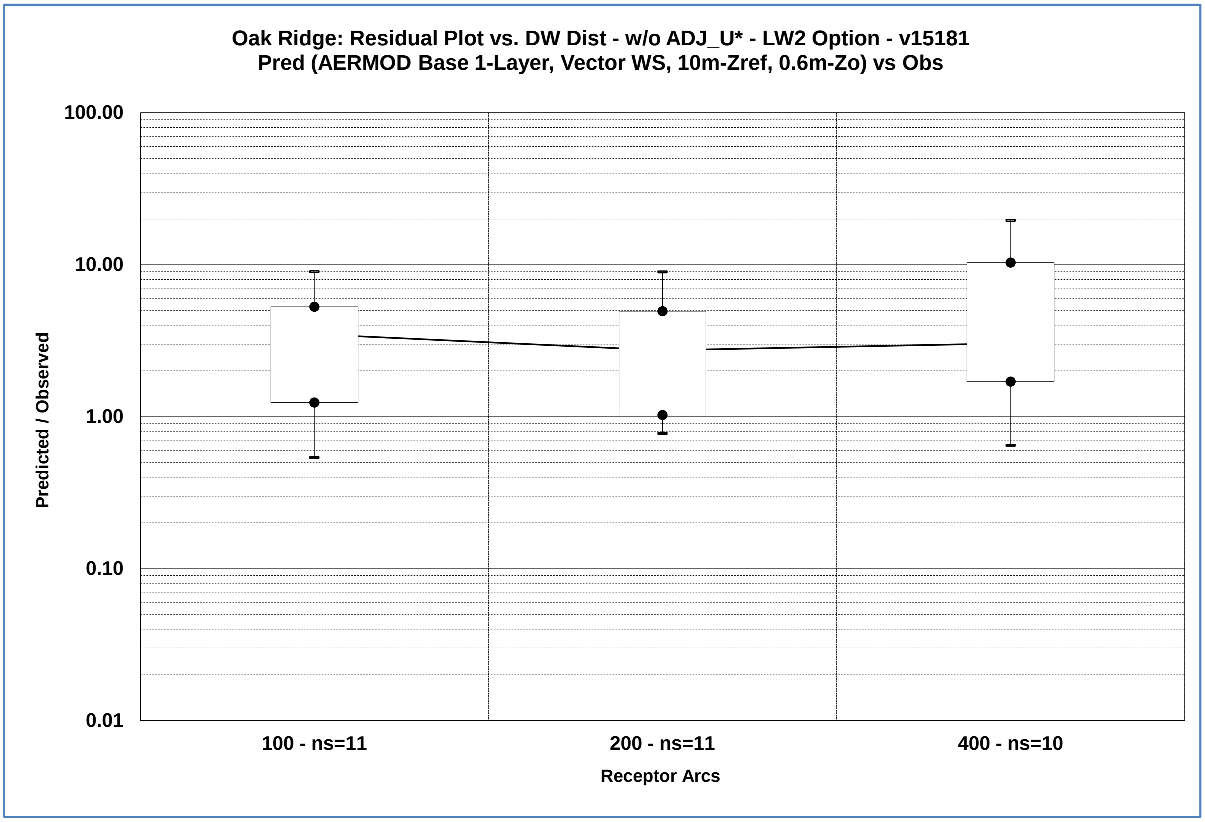
Oak Ridge: Paired Plot - With ADJ_U* - LowWind2 Option - v15181
Obs vs AERMOD (Base 1-Layer, Vector WS, 10m-Zref, 0.6m-Zo) Pred Arc-Max @ 3 DW Arcs
100-m Arc
200-m Arc
400-m Arc
Predicted (µg/m³)
Observed (µg/m³)
0
25
50
75
100



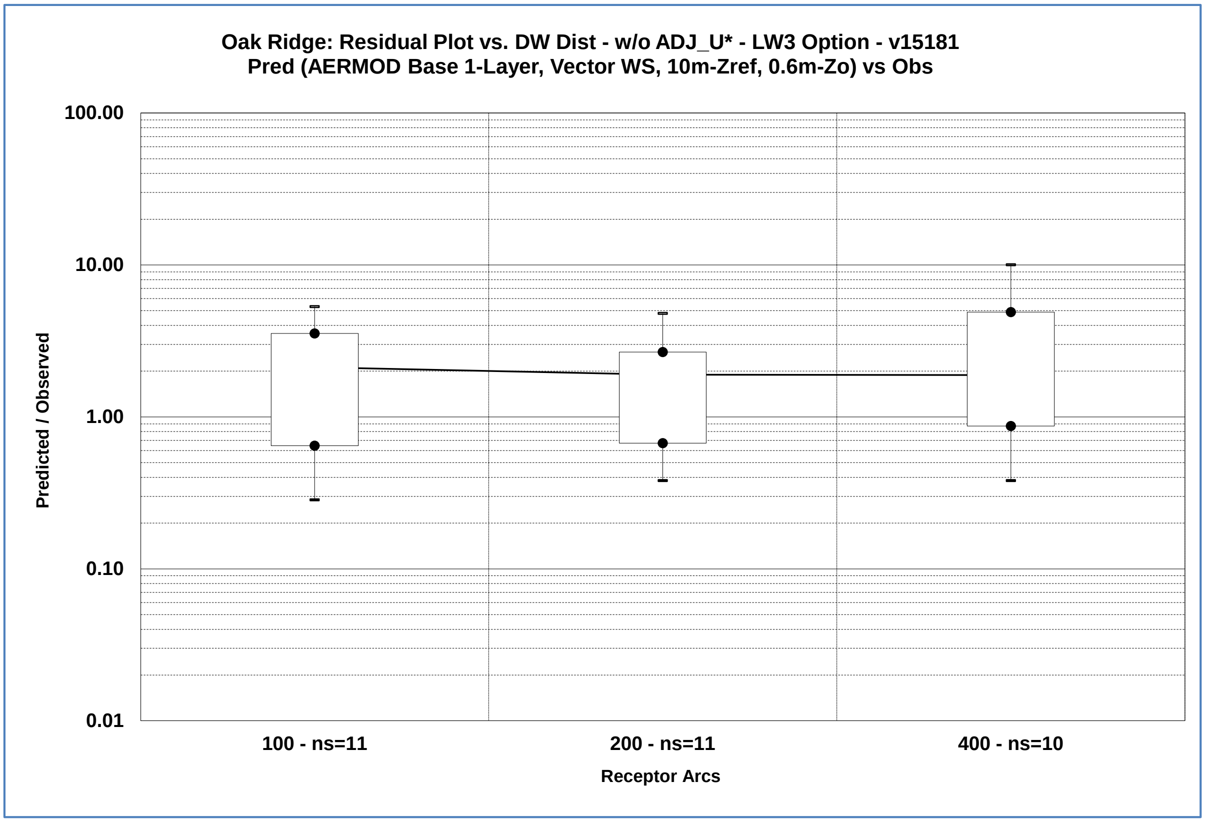
Oak Ridge: Paired Plot - With ADJ_U* - LowWind3 Opt - v15181
Obs vs AERMOD (Base 1-Layer, Vector WS, 10m-Zref, 0.6m-Zo) Pred Arc-Max @ 3 DW Arcs
100-m Arc
200-m Arc
400-m Arc
Predicted (µg/m³)
Observed (µg/m³)
0
25
50
75
100


Oak Ridge: Residual Plot vs. DW Dist - w/o ADJ_U* - NoLW Option - v15181
Pred (AERMOD Base 1-Layer, Vector WS, 10m-Zref, 0.6m-Zo) vs Obs
100.00
10.00
1.00
0.10
0.01
Predicted / Observed
100 - ns=11
200 - ns=11
400 - ns=10
Receptor Arcs

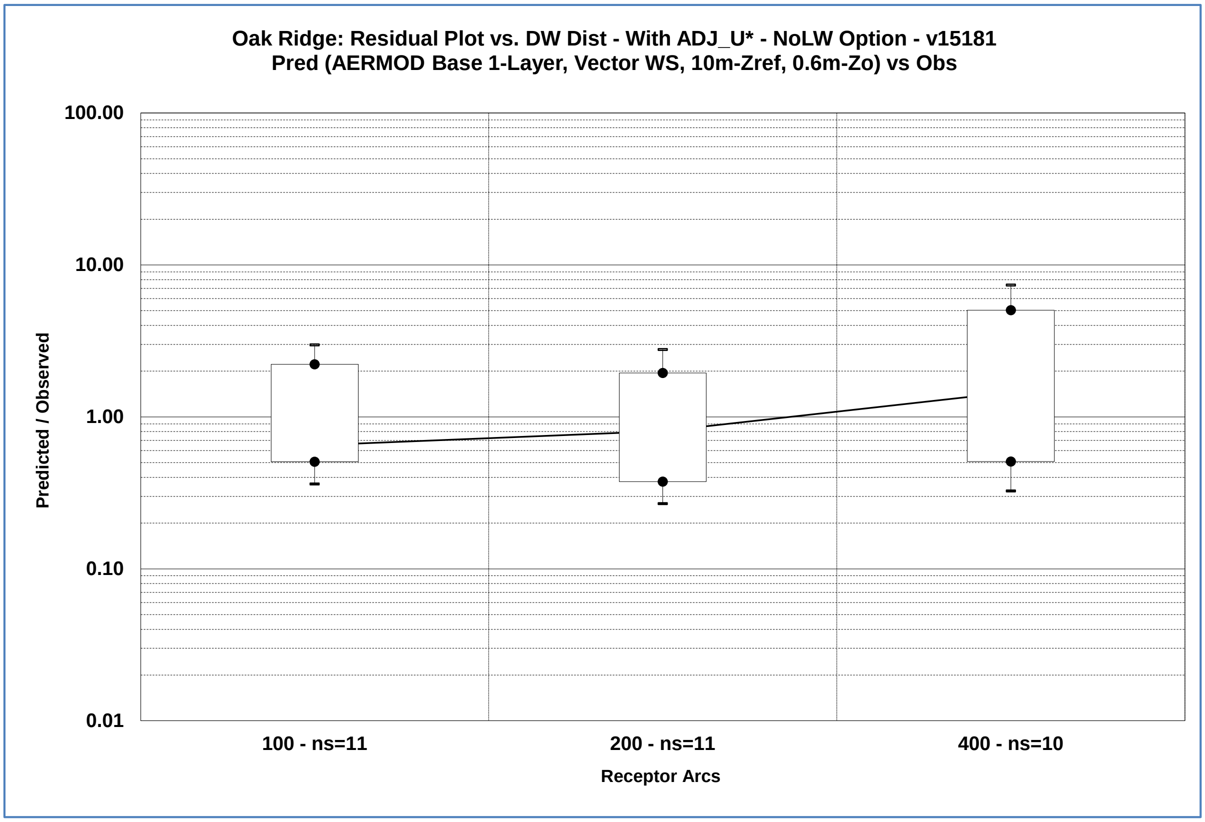

Oak Ridge: Residual Plot vs. DW Dist - w/o ADJ_U* - LW1 Option - v15181
Pred (AERMOD Base 1-Layer, Vector WS, 10m-Zref, 0.6m-Zo) vs Obs
100.00
10.00
1.00
0.10
0.01
Predicted / Observed
100 - ns=11
200 - ns=11
400 - ns=10
Receptor Arcs

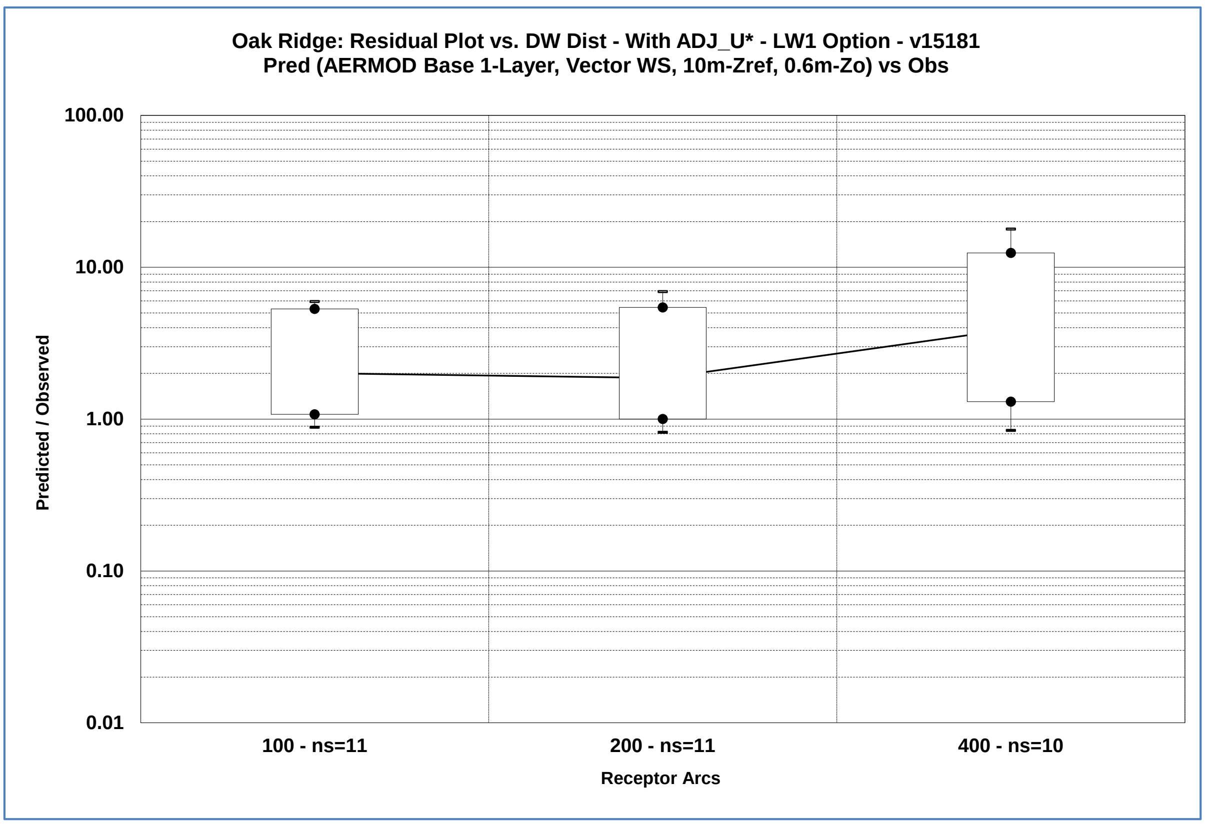


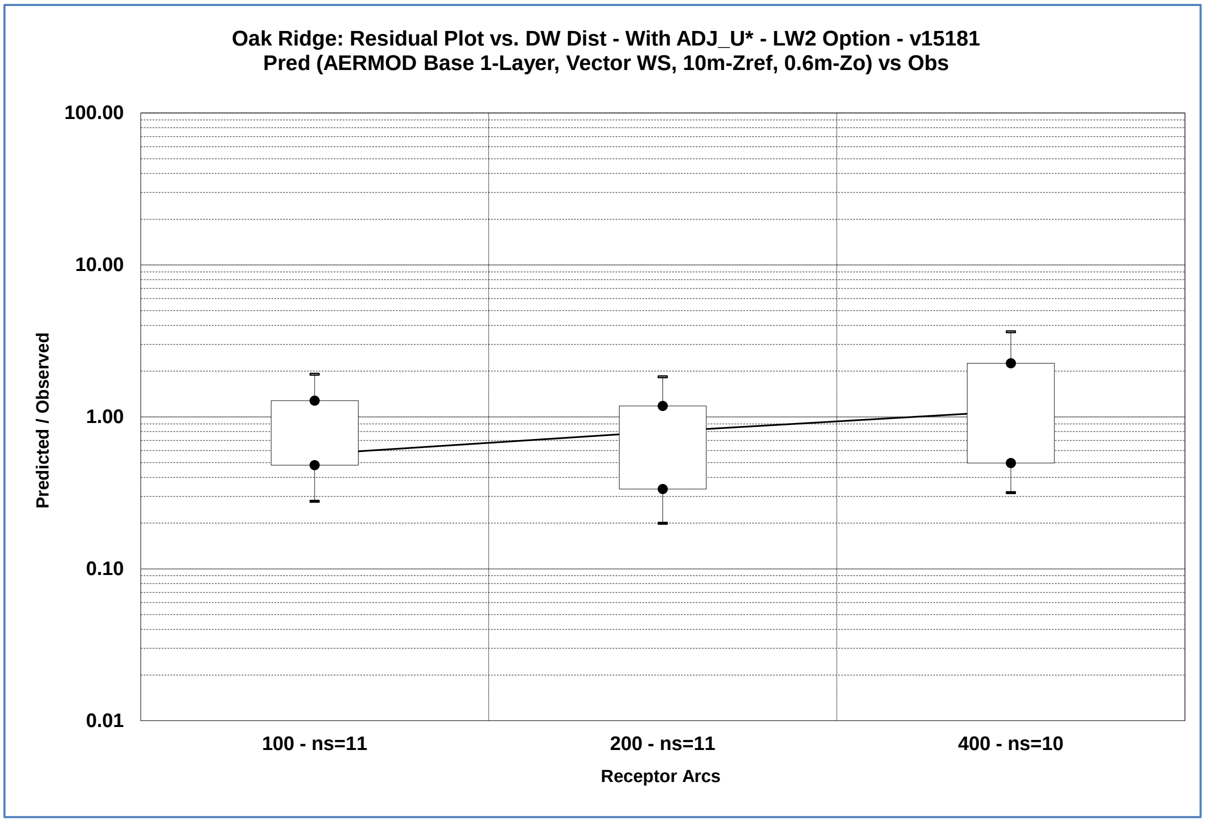
Oak Ridge: Residual Plot vs. DW Dist - w/o ADJ_U* - LW2 Option - v15181
Pred (AERMOD Base 1-Layer, Vector WS, 10m-Zref, 0.6m-Zo) vs Obs
100.00
10.00
1.00
0.10
0.01
Predicted / Observed
100 - ns=11
200 - ns=11
400 - ns=10
Receptor Arcs

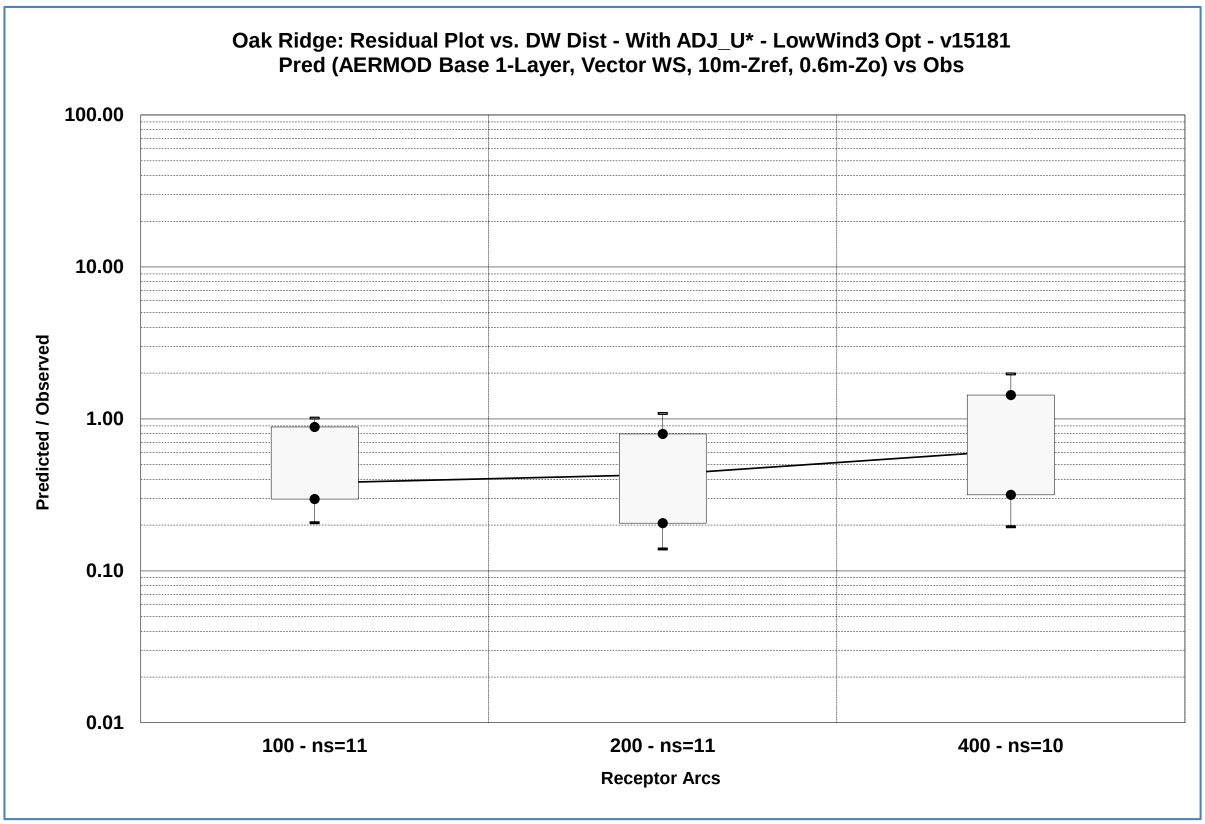


Oak Ridge: Residual Plot vs. DW Dist - w/o ADJ_U* - LW3 Option - v15181
Pred (AERMOD Base 1-Layer, Vector WS, 10m-Zref, 0.6m-Zo) vs Obs
100.00
10.00
1.00
0.10
0.01
Predicted / Observed
100 - ns=11
200 - ns=11
400 - ns=10
Receptor Arcs


Oak Ridge: Residual Plot vs. DW Dist - With ADJ_U* - NoLW Option - v15181
Pred (AERMOD Base 1-Layer, Vector WS, 10m-Zref, 0.6m-Zo) vs Obs
100.00
10.00
1.00
0.10
0.01
Predicted / Observed
100 - ns=11
200 - ns=11
400 - ns=10
Receptor Arcs


Oak Ridge: Residual Plot vs. DW Dist - With ADJ_U* - LW1 Option - v15181
Pred (AERMOD Base 1-Layer, Vector WS, 10m-Zref, 0.6m-Zo) vs Obs
100.00
10.00
1.00
0.10
0.01
Predicted / Observed
100 - ns=11
200 - ns=11
400 - ns=10
Receptor Arcs


Oak Ridge: Residual Plot vs. DW Dist - With ADJ_U* - LW2 Option - v15181
Pred (AERMOD Base 1-Layer, Vector WS, 10m-Zref, 0.6m-Zo) vs Obs
100.00
10.00
1.00
0.10
0.01
Predicted / Observed
100 - ns=11
200 - ns=11
400 - ns=10
Receptor Arcs


Oak Ridge: Residual Plot vs. DW Dist - With ADJ_U* - LowWind3 Opt - v15181
Pred (AERMOD Base 1-Layer, Vector WS, 10m-Zref, 0.6m-Zo) vs Obs
100.00
10.00
1.00
0.10
0.01
Predicted / Observed
100 - ns=11
200 - ns=11
400 - ns=10
Receptor Arcs

The figures shown above for the Oak Ridge field study show significant overprediction with the current default options in AERMET and AERMOD. The LowWind2 and LowWind3 options without the ADJ_U* option exhibit much better performance, with LowWind3 showing the best results, but both options still show significant overpredictions. The LowWind1 option actually degrades model performance relative to the default options. These figures also show significant improvement in model performance with the ADJ_U* option in AERMET with and without the LowWind options. The LowWind2 option with ADJ_U* appears to show the best overall performance, with the LownWind3/ADJ_U* option showing some bias toward underprediction. However, as noted above, the evaluation results presented here do not account for the potential influence of terrain on modeled concentrations. Given the potential for valley channeling and drainage flows one might expect modeling results based on an assumption of flat terrain to underestimate concentrations for this study. Figure 7 from the NOAA Technical Memorandum shows horizontal isopleths of concentrations for Test #6 which appears to be stretched along the axis of the valley where the tracer was released. A similar pattern shows up with other tests.

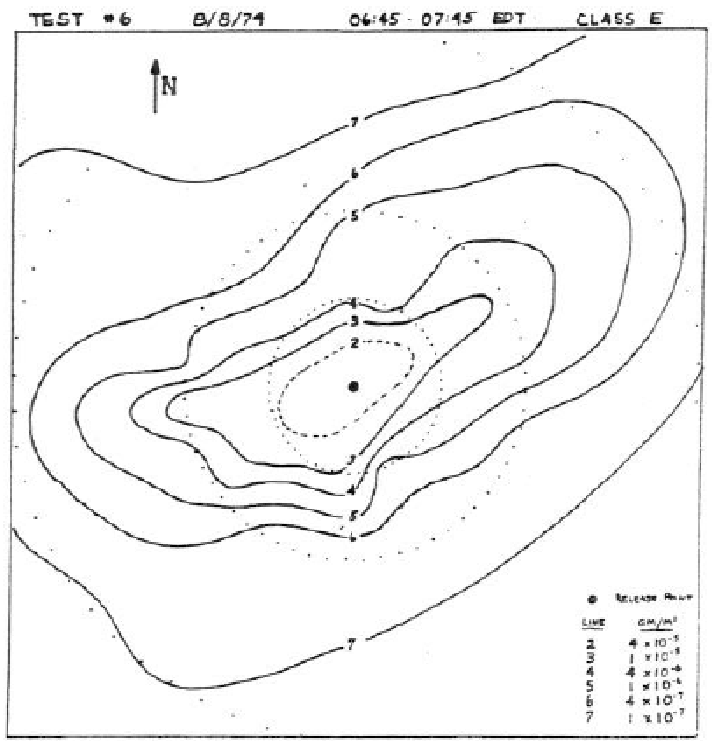
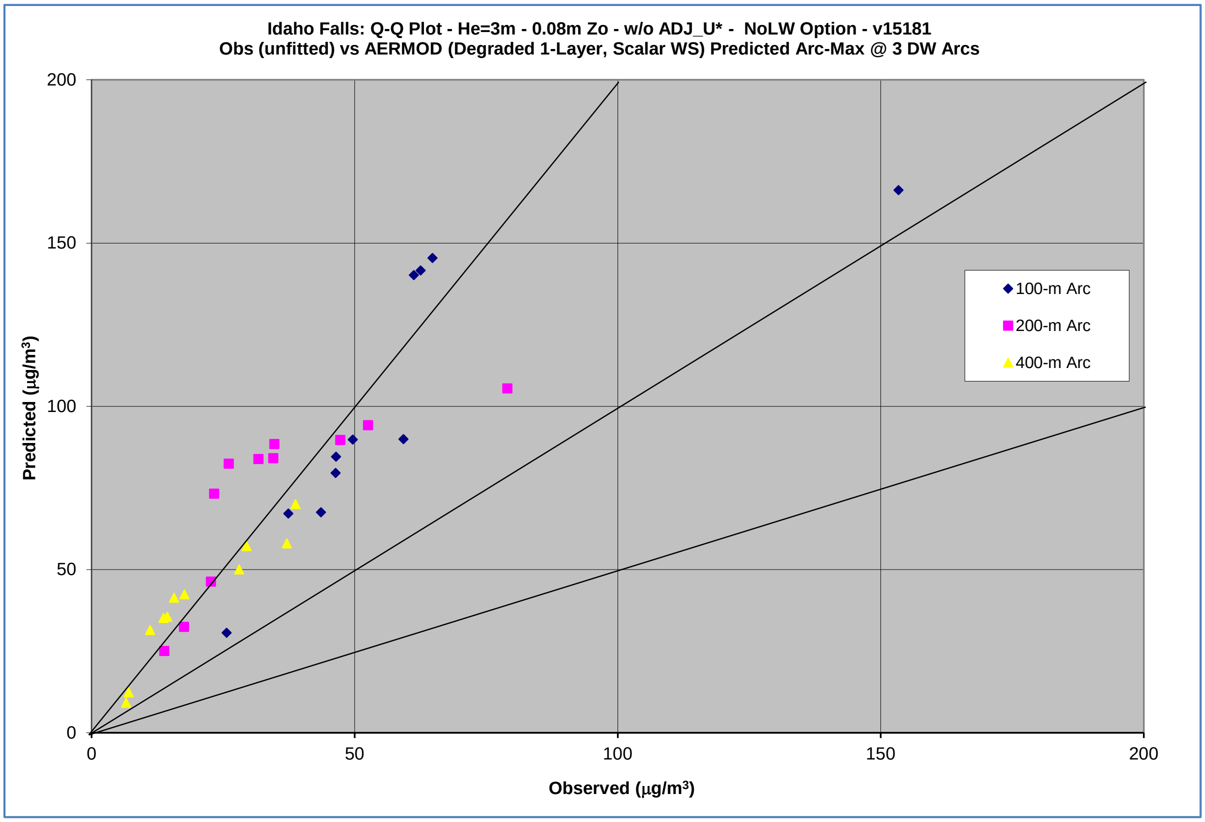
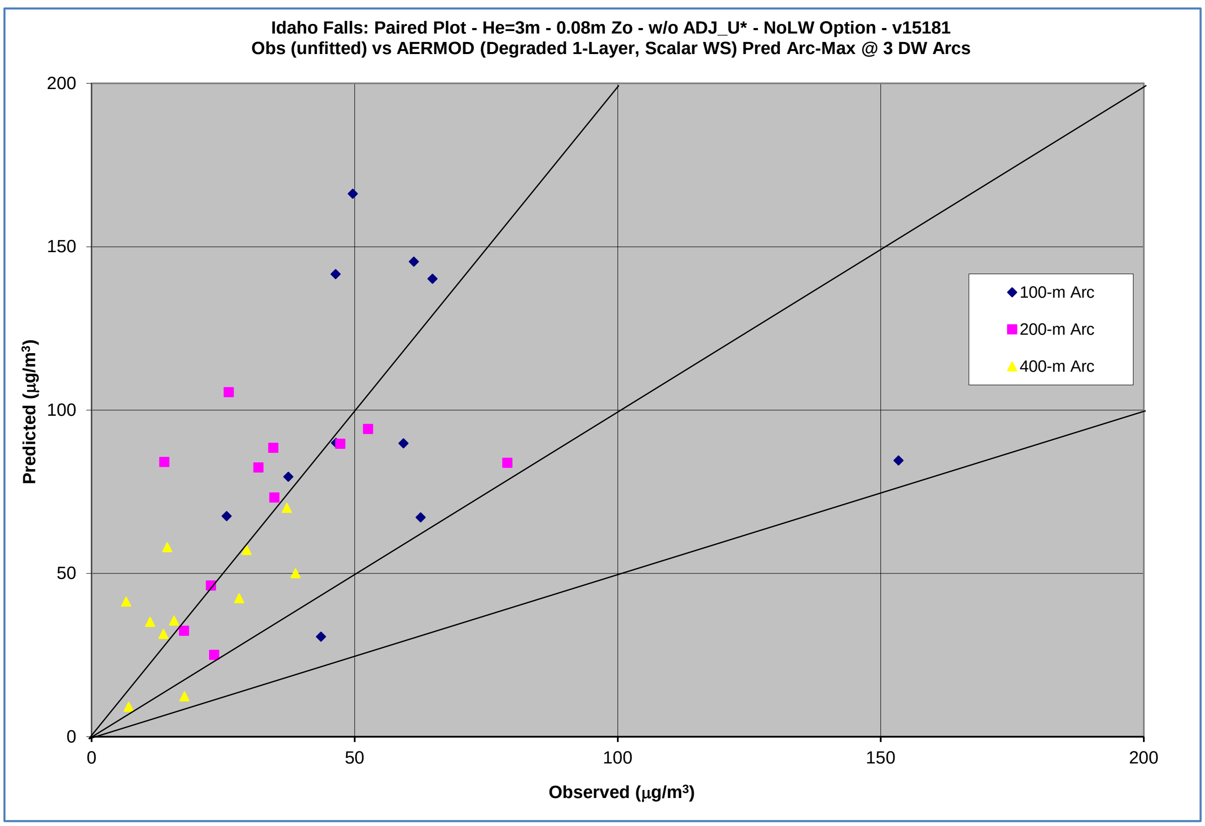


Figure 7. Horizontal isopleths of concentration for test 6 showing the typical 360° spread of gaseous tracer.

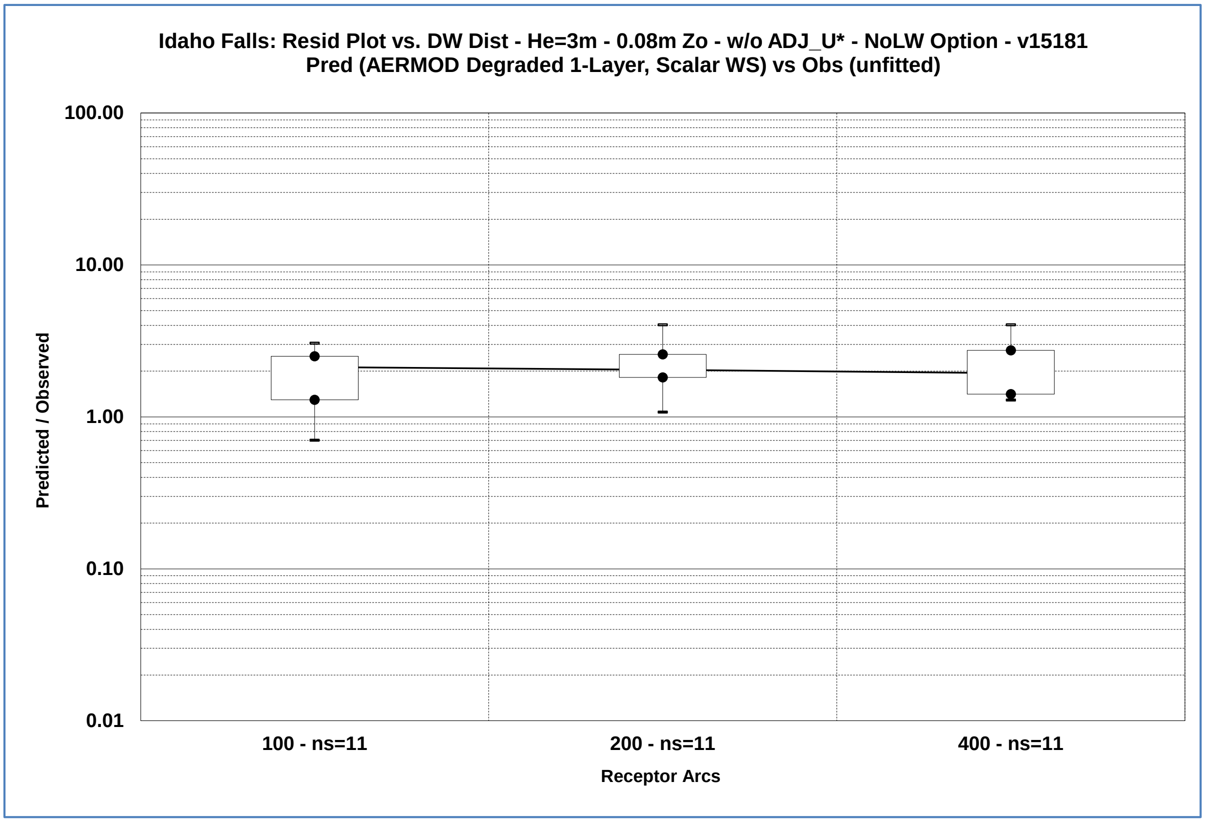
The next series of figures shows evaluation results for Idaho Falls based on the degraded 1-layer meteorological data (i.e., no delta-T data for the BULKRN option and no sigma-theta data, starting with the DFAULT option (without ADJ_U* and NoLW), followed by the LowWind1, LowWind2, and LowWind3 option, followed by the results with the ADJ_U* option.



Idaho Falls: Q-Q Plot - He=3m - 0.08m Zo - w/o ADJ_U* - NoLW Option - v15181
Obs (unfitted) vs AERMOD (Degraded 1-Layer, Scalar WS) Predicted Arc-Max @ 3 DW Arcs
Predicted (μg/m³)
Observed (μg/m³)
0
50
100
150
200
100-m Arc
200-m Arc
400-m Arc

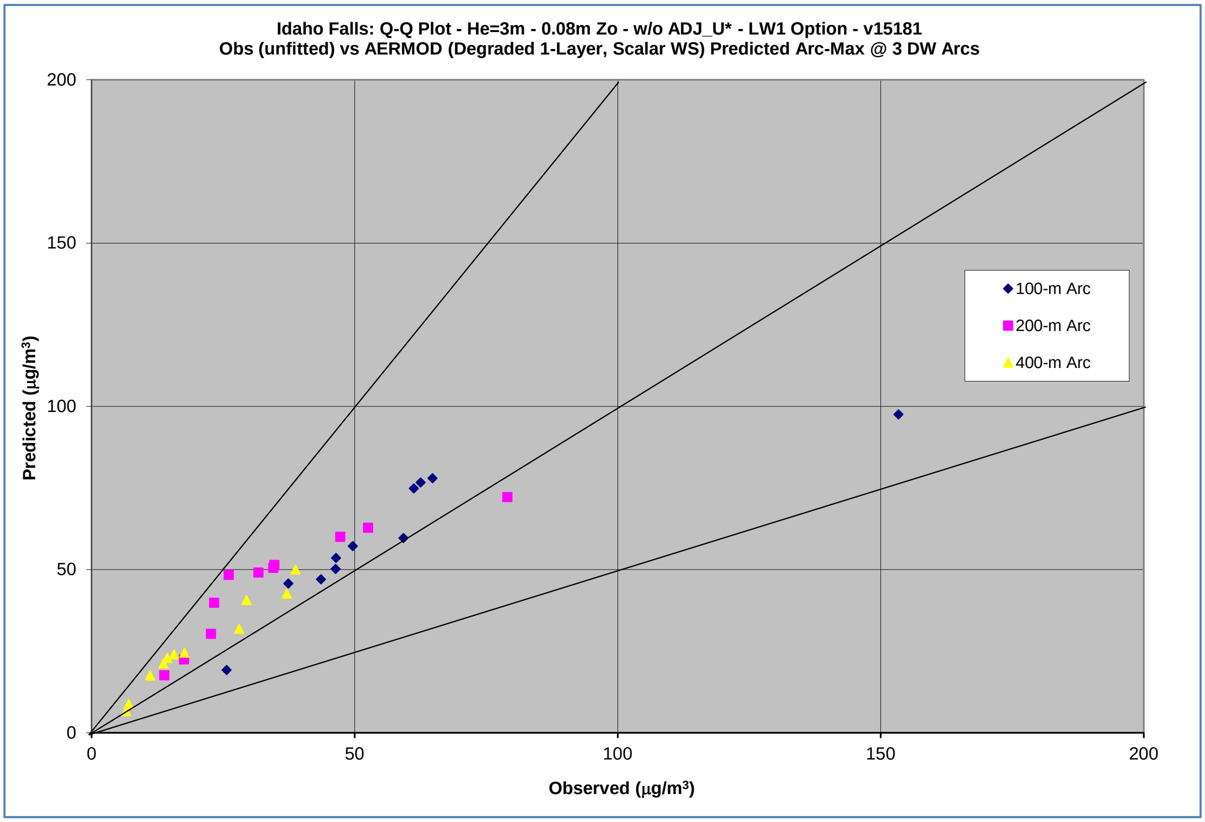


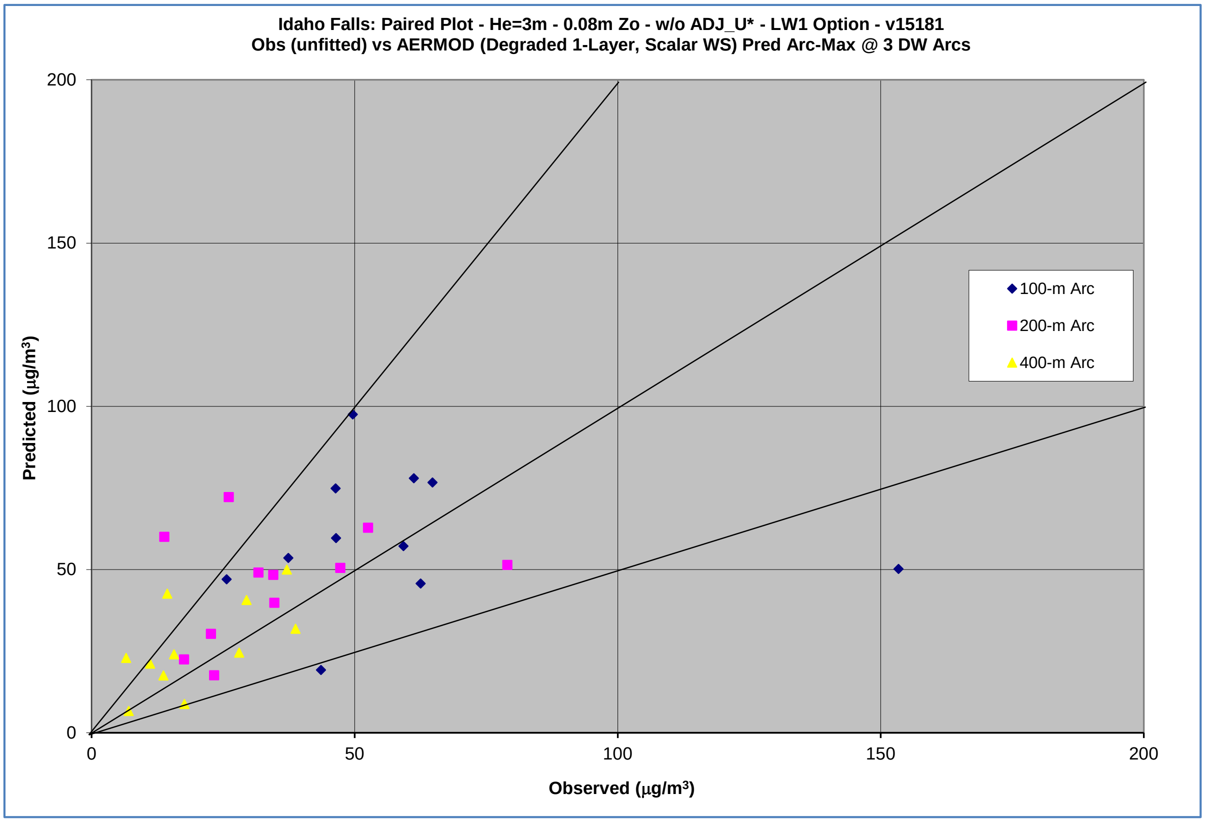
Idaho Falls: Paired Plot - He=3m - 0.08m Zo - w/o ADJ_U* - NoLW Option - v15181
Obs (unfitted) vs AERMOD (Degraded 1-Layer, Scalar WS) Pred Arc-Max @ 3 DW Arcs
Predicted (μg/m³)
Observed (μg/m³)
0
50
100
150
200
100-m Arc
200-m Arc
400-m Arc

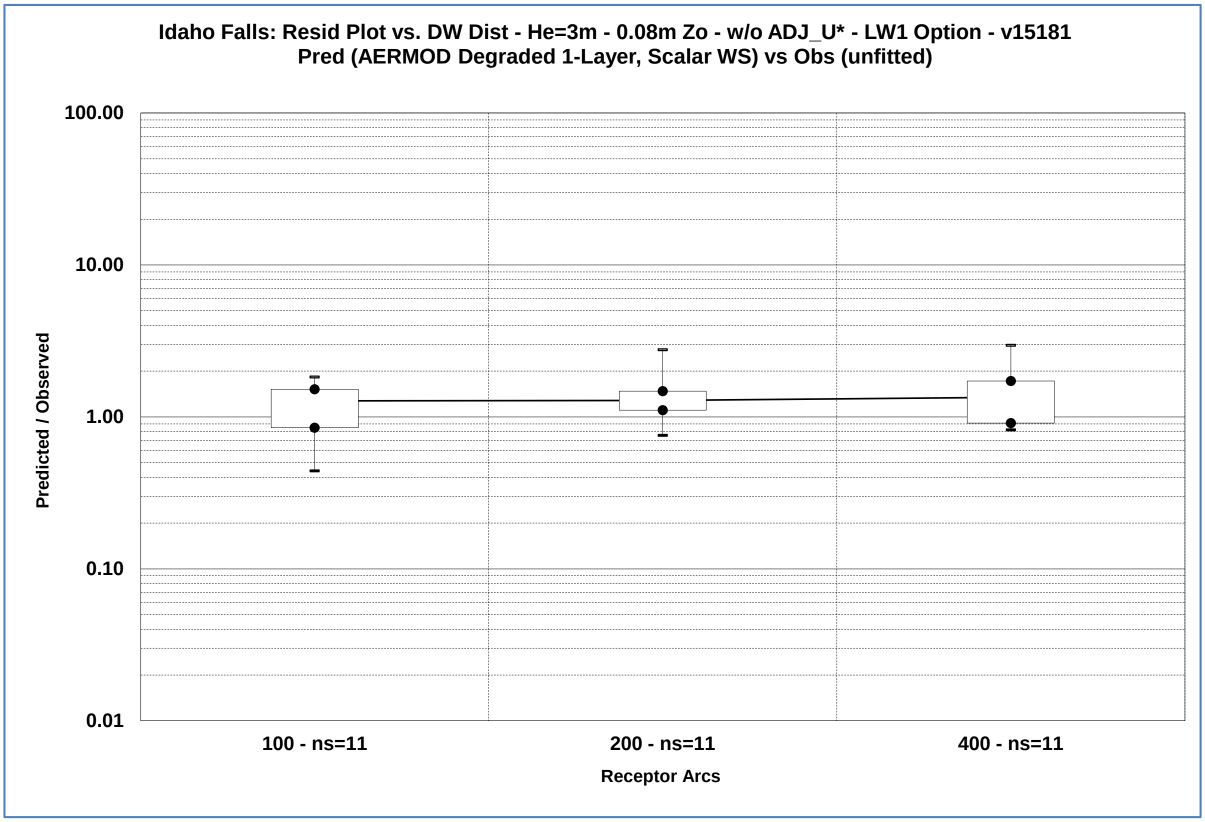


The results for Idaho Falls based on the default options in AERMET and AERMOD exhibit overprediction of the observed concentrations of approximately a factor of 2, with is a much smaller bias than for the Oak Ridge study. As shown below, the bias toward overprediction is largely eliminated with the LowWind options in AERMOD, without the ADJ_U* option in AERMET. The average Pred/Obs concentration ratios are also generally consistent with downwind distance.

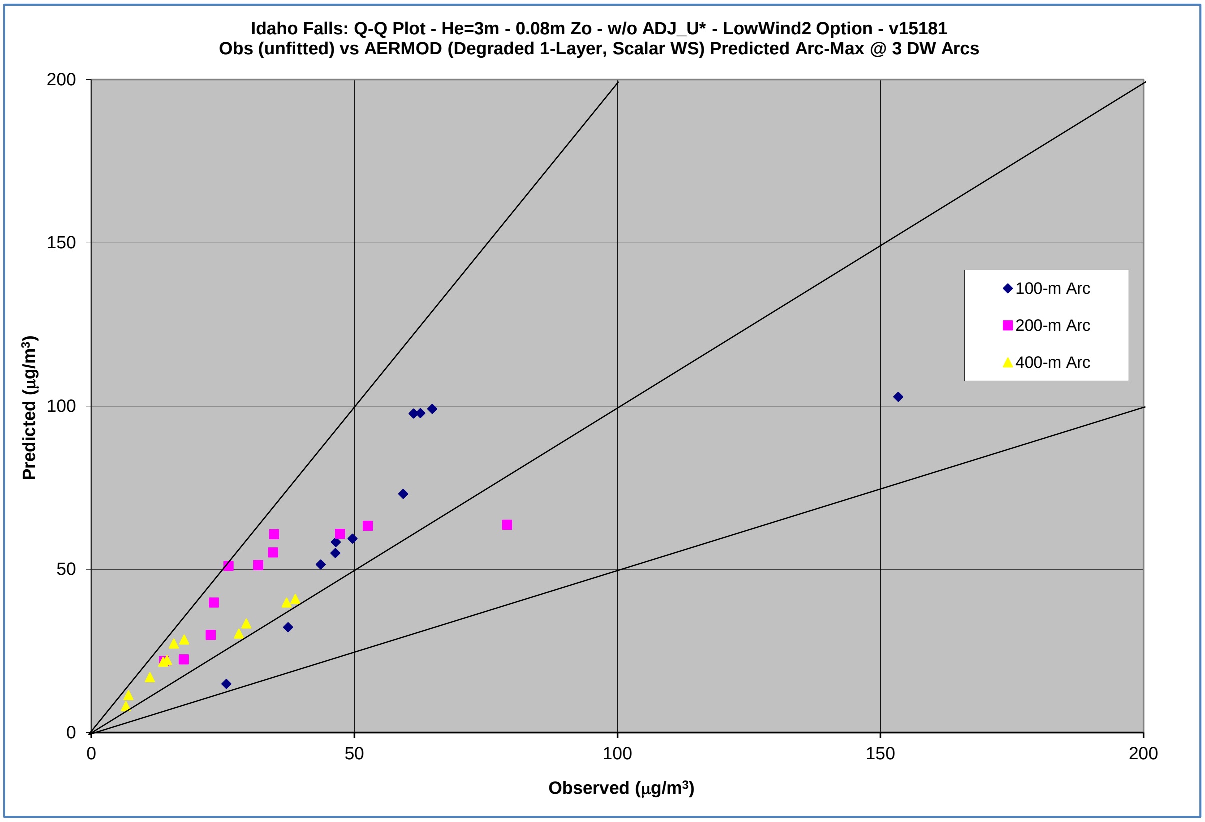
The results for Idaho Falls with the ADJ_U* option in AERMET also show generally good performance at the first arc of receptors at 100m downwind, with some tendency toward underprediction further downwind, especially when the LowWind options are also used. For this type of source, i.e., a non-buoyant, ground-level or low-level source (e.g., fugitive emission), the maximum ambient impacts are likely to occur at the fenceline.

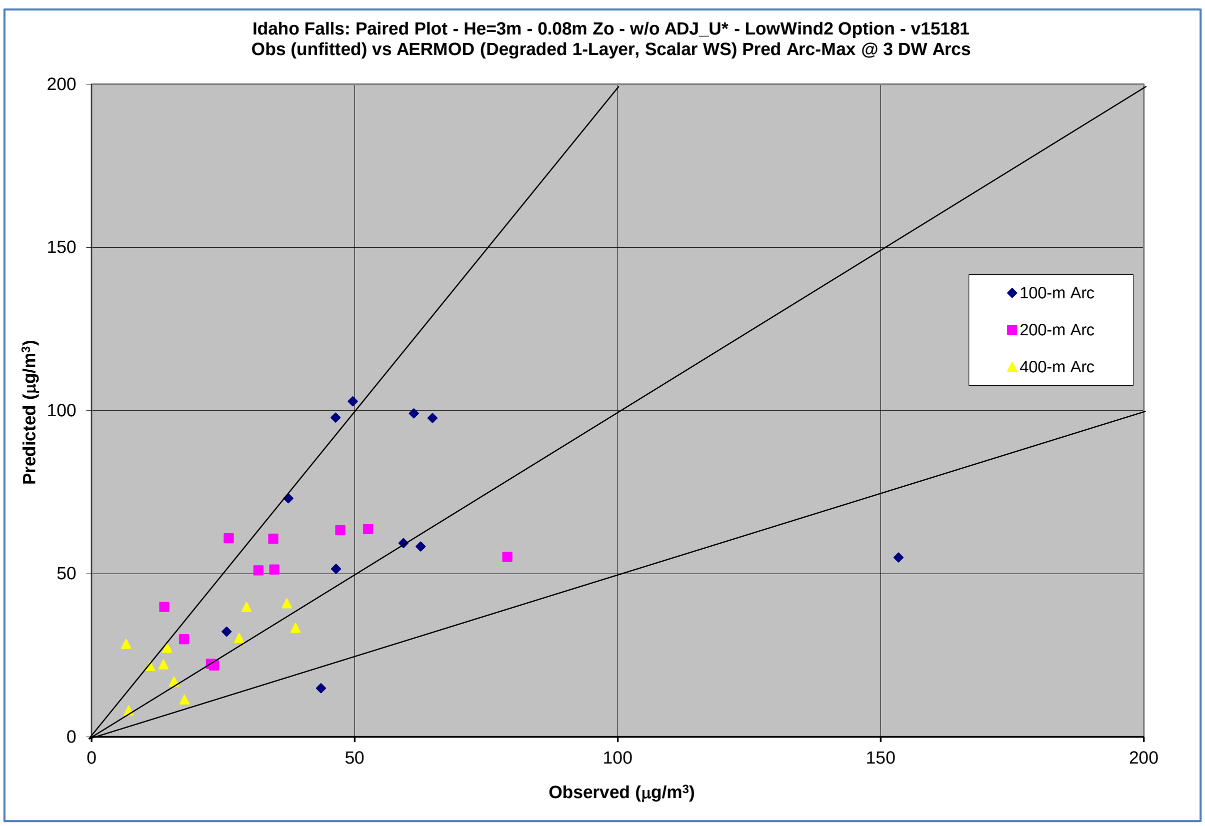

Idaho Falls: Q-Q Plot - He=3m - 0.08m Zo - w/o ADJ_U* - LW1 Option - v15181
Obs (unfitted) vs AERMOD (Degraded 1-Layer, Scalar WS) Predicted Arc-Max @ 3 DW Arcs
Predicted (µg/m³)
Observed (µg/m³)
100-m Arc
200-m Arc
400-m Arc
0
50
100
150
200

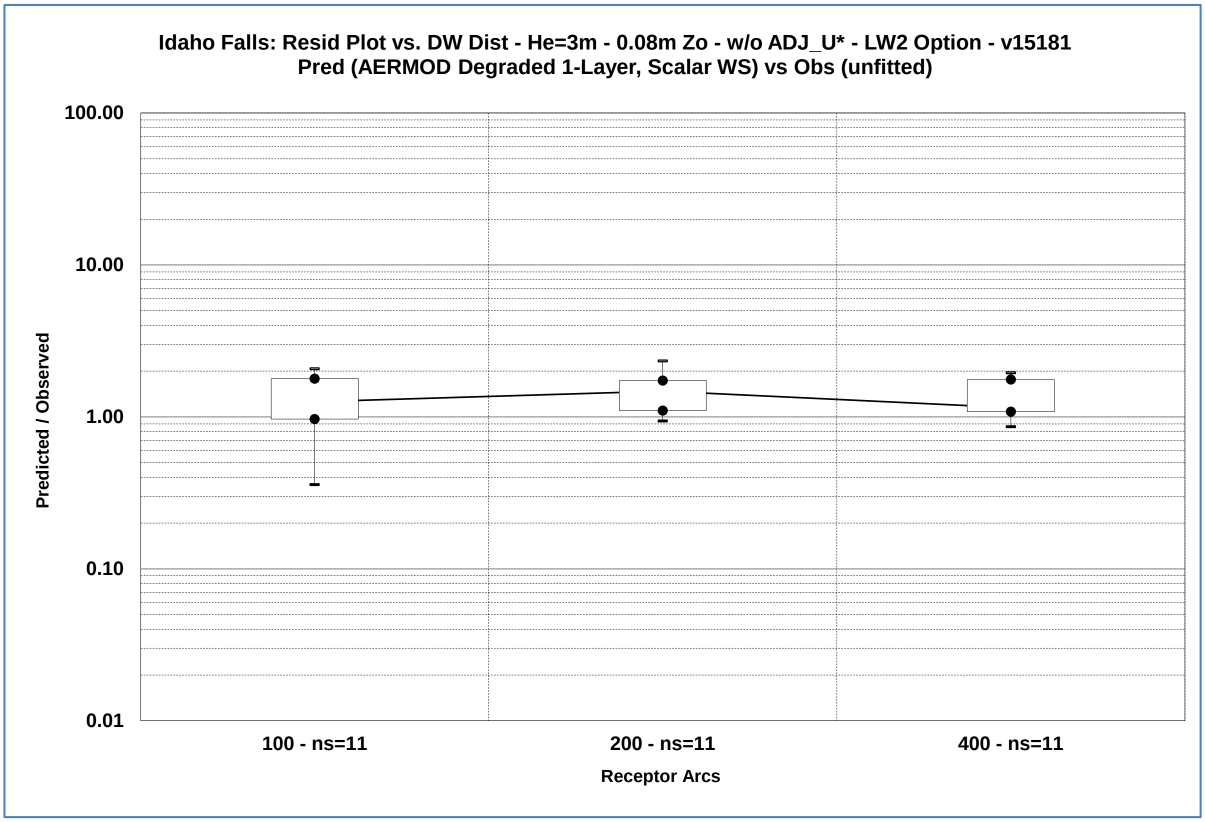

Idaho Falls: Paired Plot - He=3m - 0.08m Zo - w/o ADJ_U* - LW1 Option - v15181
Obs (unfitted) vs AERMOD (Degraded 1-Layer, Scalar WS) Pred Arc-Max @ 3 DW Arcs
Predicted (µg/m³)
Observed (µg/m³)
100-m Arc
200-m Arc
400-m Arc
0
50
100
150
200

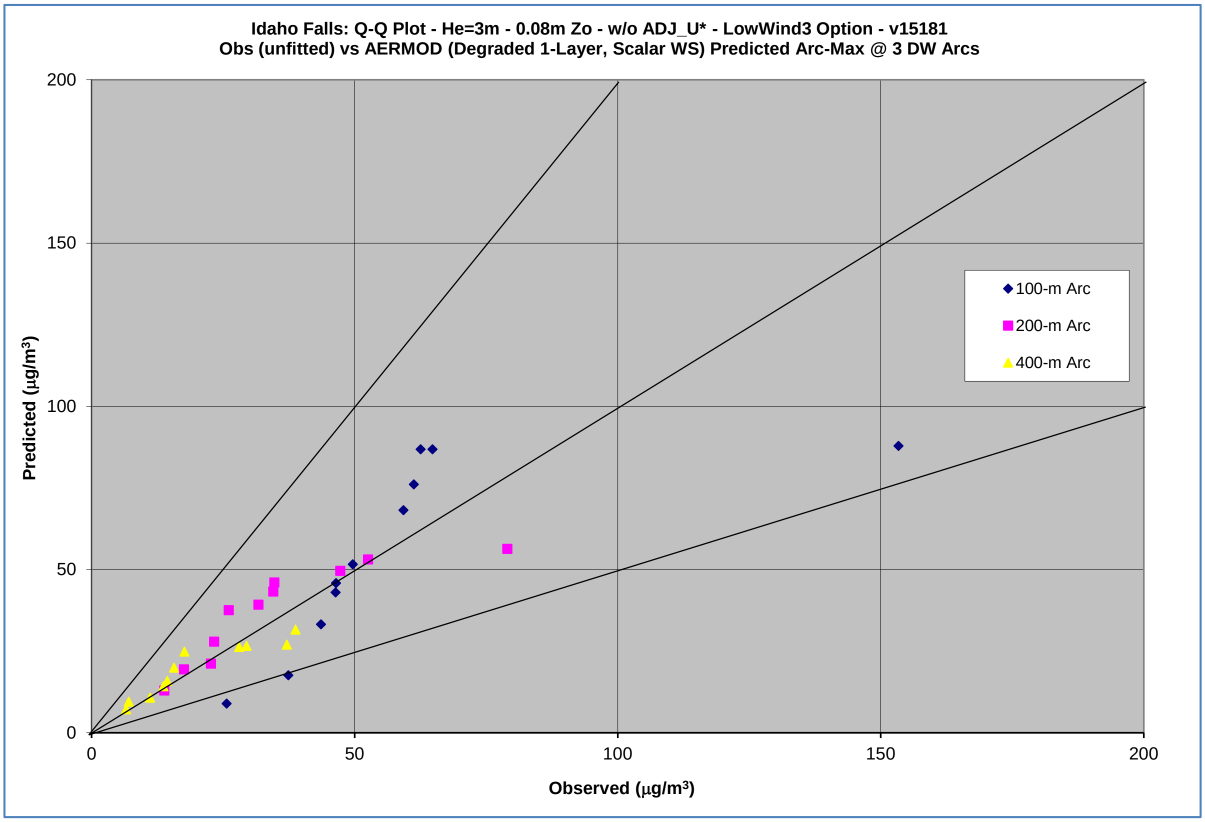


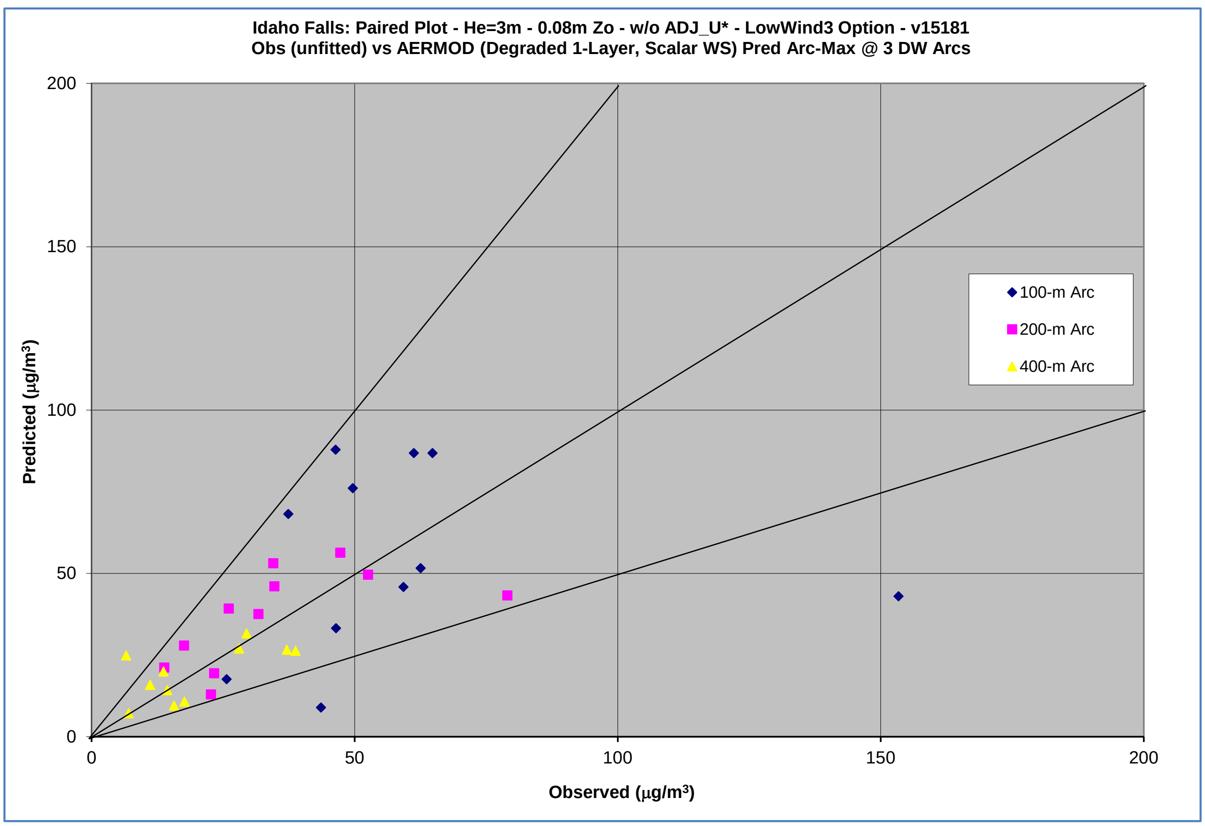
Idaho Falls: Resid Plot vs. DW Dist - He=3m - 0.08m Zo - w/o ADJ_U* - LW1 Option - v15181
Pred (AERMOD Degraded 1-Layer, Scalar WS) vs Obs (unfitted)
100.00
10.00
1.00
0.10
0.01
Predicted / Observed
100 - ns=11
200 - ns=11
400 - ns=11
Receptor Arcs

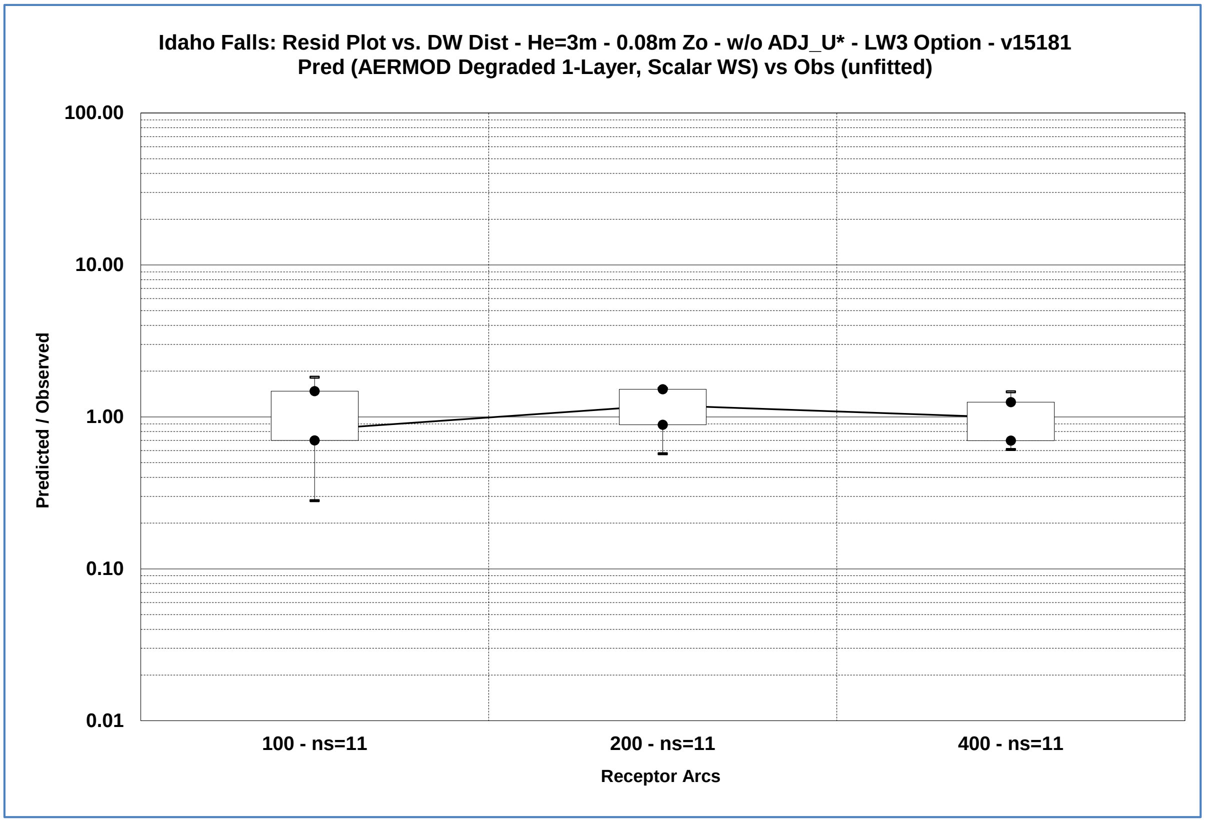

Idaho Falls: Q-Q Plot - He=3m - 0.08m Zo - w/o ADJ_U* - LowWind2 Option - v15181
Obs (unfitted) vs AERMOD (Degraded 1-Layer, Scalar WS) Predicted Arc-Max @ 3 DW Arcs
Predicted (µg/m³)
Observed (µg/m³)
100-m Arc
200-m Arc
400-m Arc
0
50
100
150
200

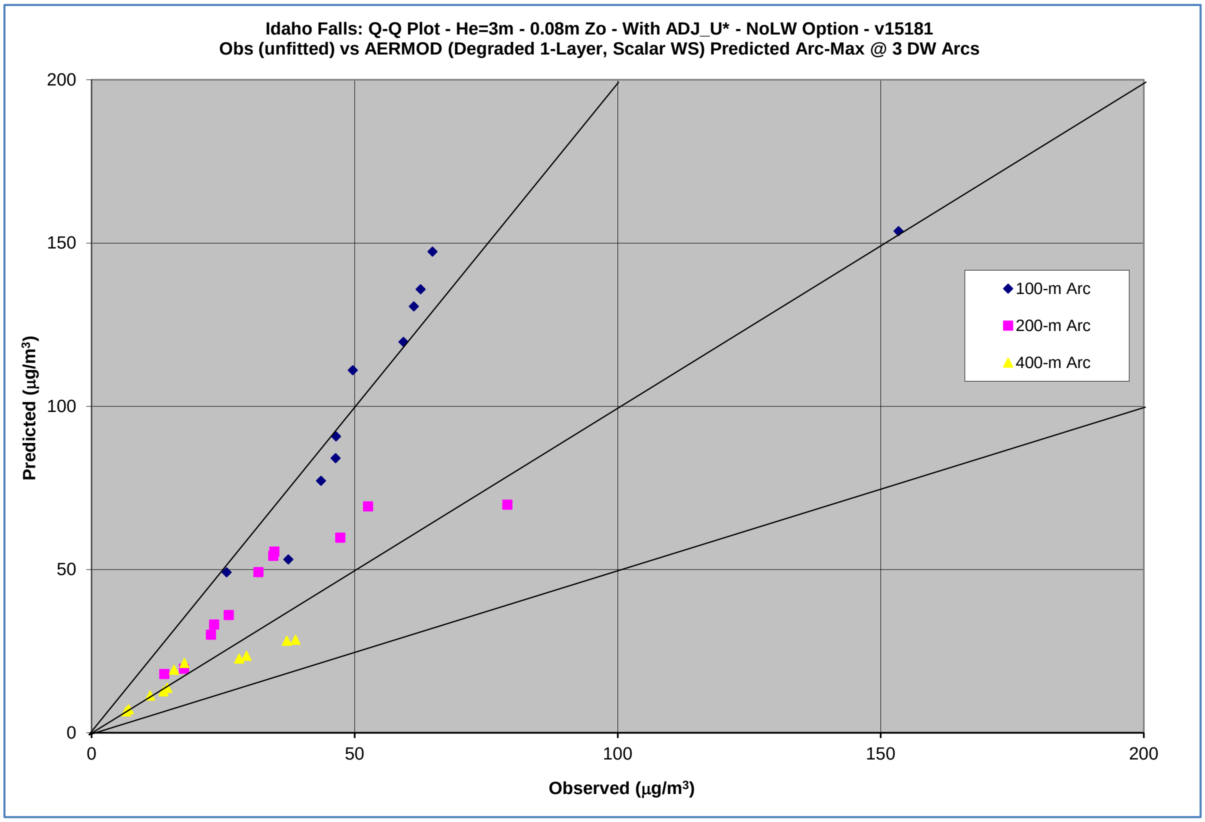

Idaho Falls: Paired Plot - He=3m - 0.08m Zo - w/o ADJ_U* - LowWind2 Option - v15181
Obs (unfitted) vs AERMOD (Degraded 1-Layer, Scalar WS) Pred Arc-Max @ 3 DW Arcs
Predicted (µg/m³)
Observed (µg/m³)
100-m Arc
200-m Arc
400-m Arc
0
50
100
150
200

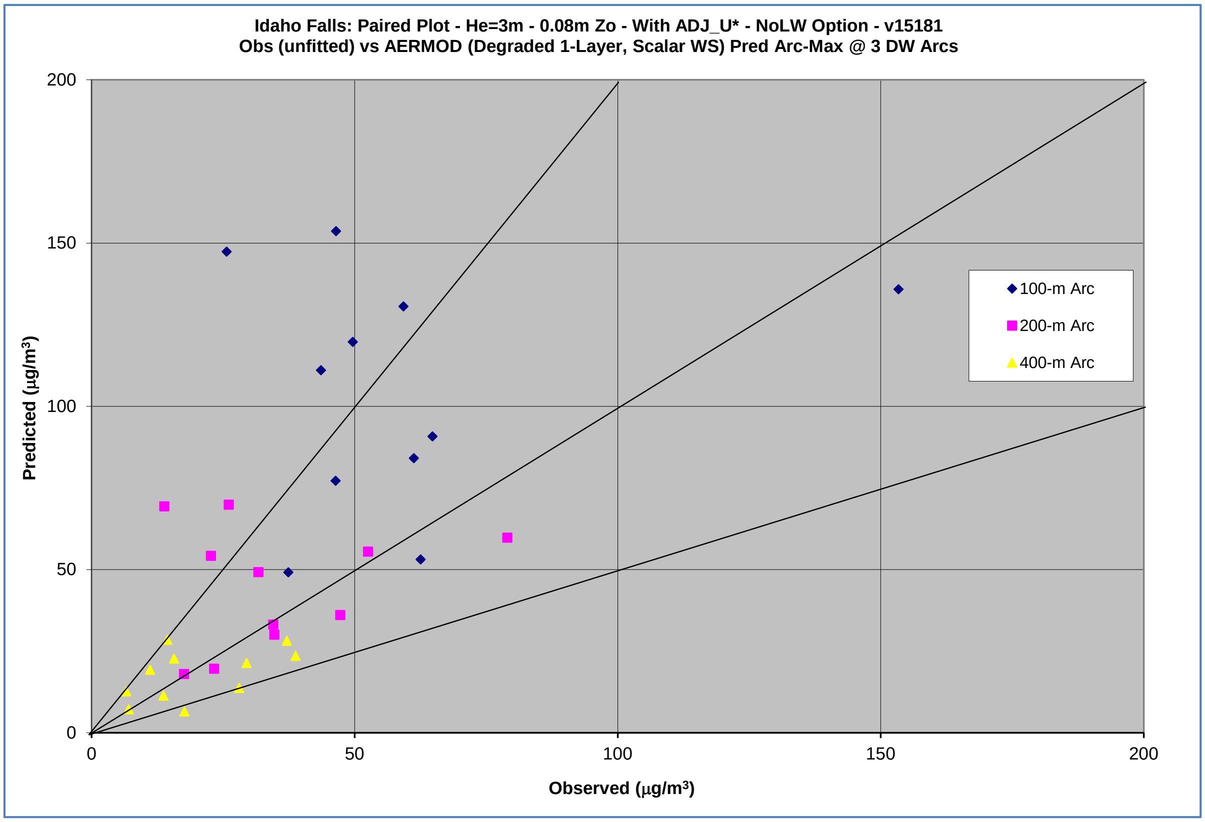

Idaho Falls: Resid Plot vs. DW Dist - He=3m - 0.08m Zo - w/o ADJ_U* - LW2 Option - v15181
Pred (AERMOD Degraded 1-Layer, Scalar WS) vs Obs (unfitted)
100.00
10.00
1.00
0.10
0.01
Predicted / Observed
100 - ns=11
200 - ns=11
400 - ns=11
Receptor Arcs

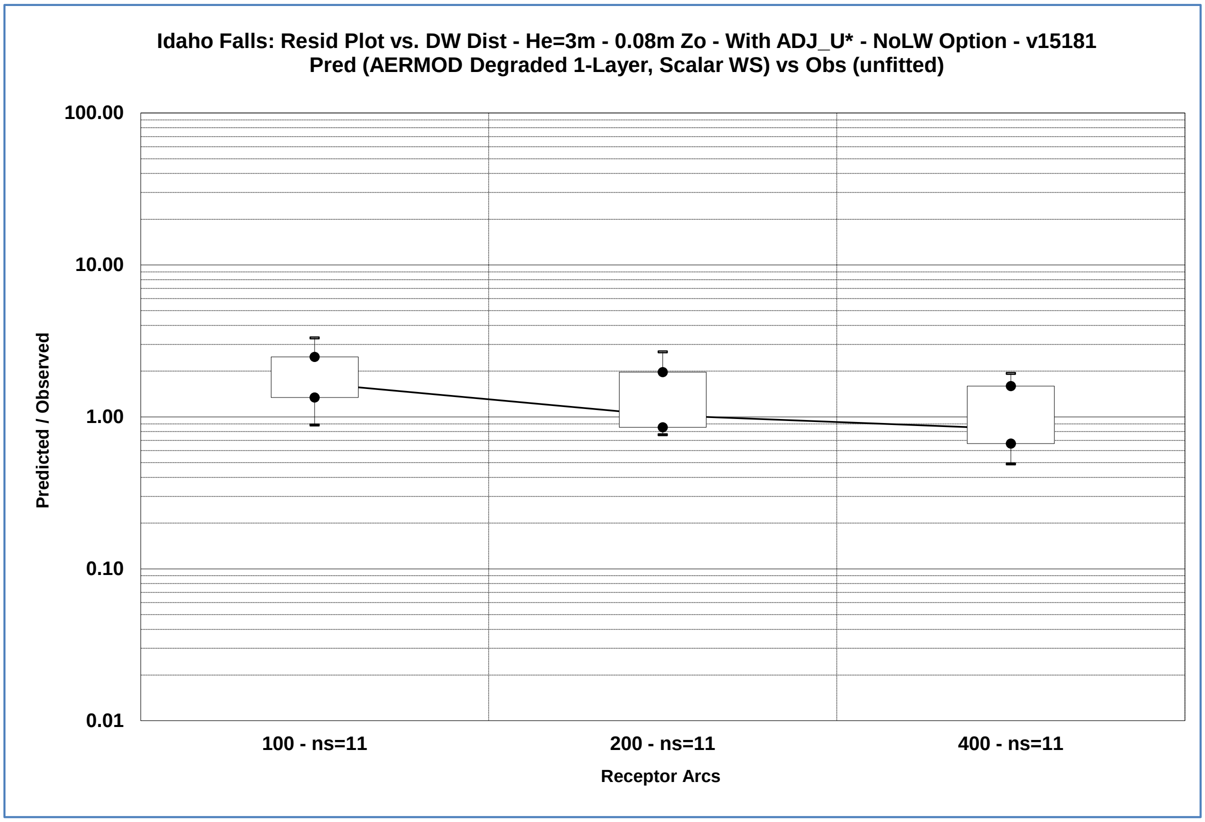

Idaho Falls: Q-Q Plot - He=3m - 0.08m Zo - w/o ADJ_U* - LowWind3 Option - v15181
Obs (unfitted) vs AERMOD (Degraded 1-Layer, Scalar WS) Predicted Arc-Max @ 3 DW Arcs
Predicted (μg/m³)
Observed (μg/m³)
0
50
100
150
200
100-m Arc
200-m Arc
400-m Arc


Idaho Falls: Paired Plot - He=3m - 0.08m Zo - w/o ADJ_U* - LowWind3 Option - v15181
Obs (unfitted) vs AERMOD (Degraded 1-Layer, Scalar WS) Pred Arc-Max @ 3 DW Arcs
Predicted (μg/m³)
Observed (μg/m³)
0
50
100
150
200
100-m Arc
200-m Arc
400-m Arc

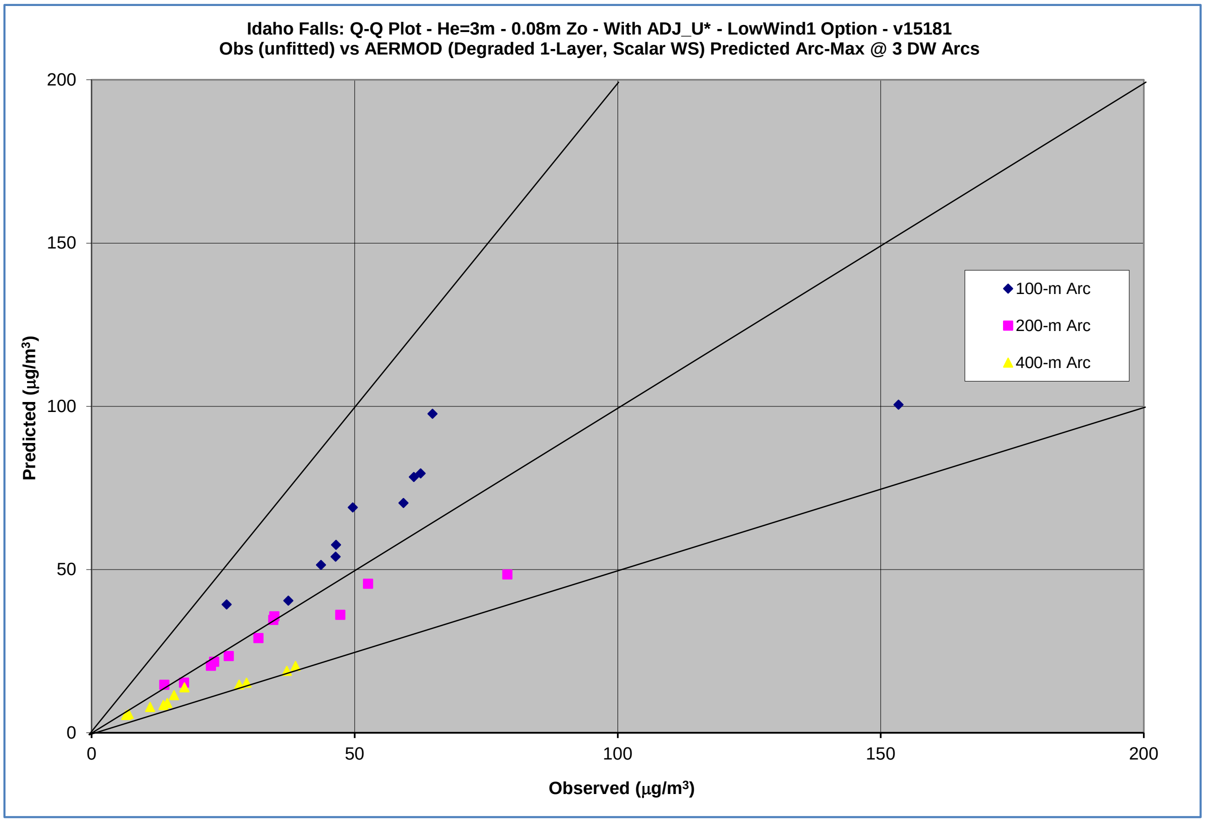

Idaho Falls: Resid Plot vs. DW Dist - He=3m - 0.08m Zo - w/o ADJ_U* - LW3 Option - v15181
Pred (AERMOD Degraded 1-Layer, Scalar WS) vs Obs (unfitted)
100.00
10.00
1.00
0.10
0.01
Predicted / Observed
100 - ns=11
200 - ns=11
400 - ns=11
Receptor Arcs

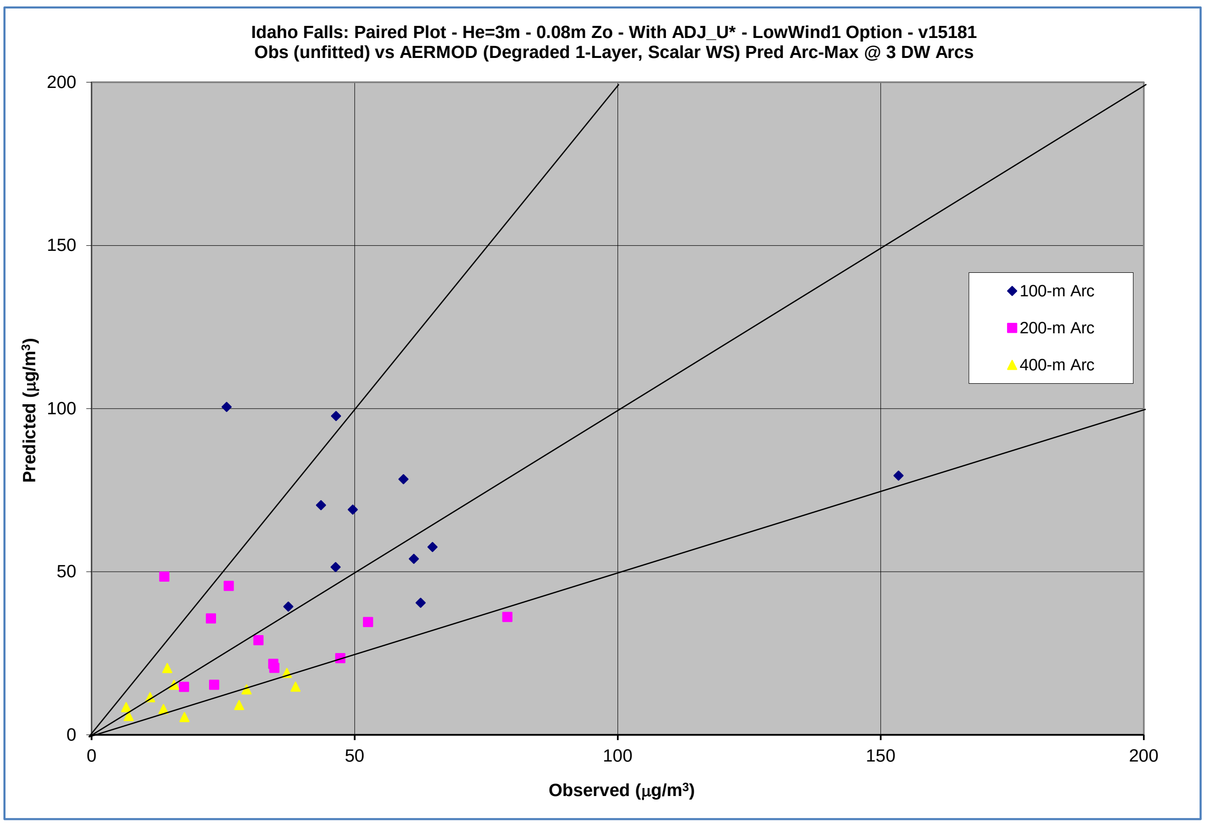

Idaho Falls: Q-Q Plot - He=3m - 0.08m Zo - With ADJ_U* - NoLW Option - v15181
Obs (unfitted) vs AERMOD (Degraded 1-Layer, Scalar WS) Predicted Arc-Max @ 3 DW Arcs
Predicted (µg/m³)
Observed (µg/m³)
0
50
100
150
200
100-m Arc
200-m Arc
400-m Arc

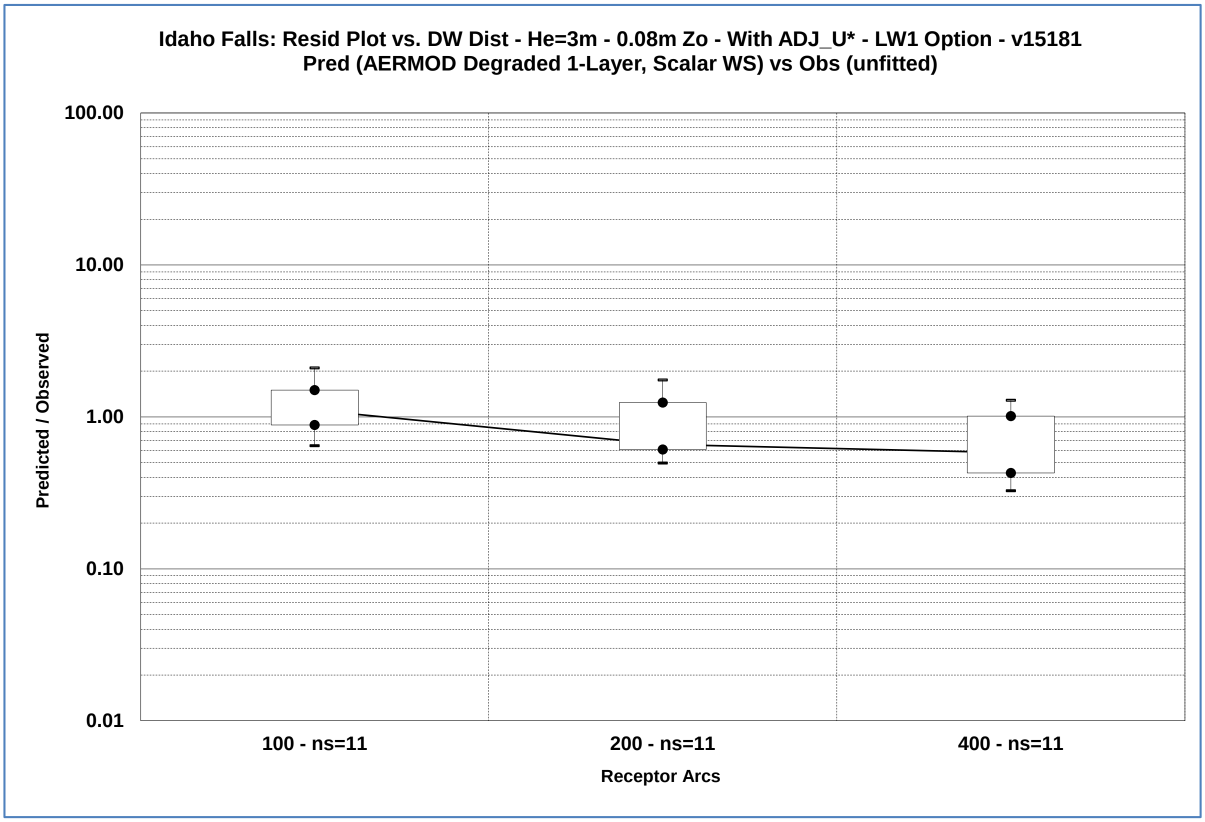

Idaho Falls: Paired Plot - He=3m - 0.08m Zo - With ADJ_U* - NoLW Option - v15181
Obs (unfitted) vs AERMOD (Degraded 1-Layer, Scalar WS) Pred Arc-Max @ 3 DW Arcs
Predicted (µg/m³)
Observed (µg/m³)
0
50
100
150
200
100-m Arc
200-m Arc
400-m Arc

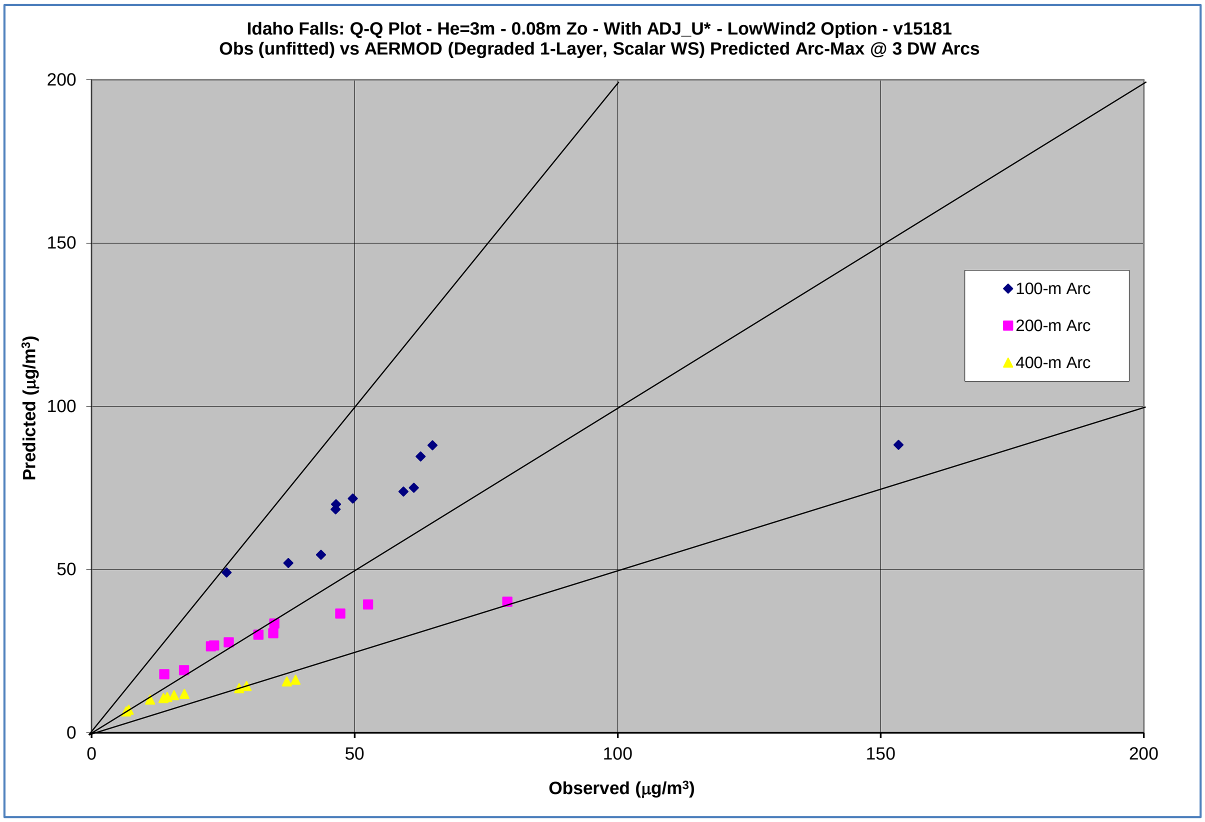


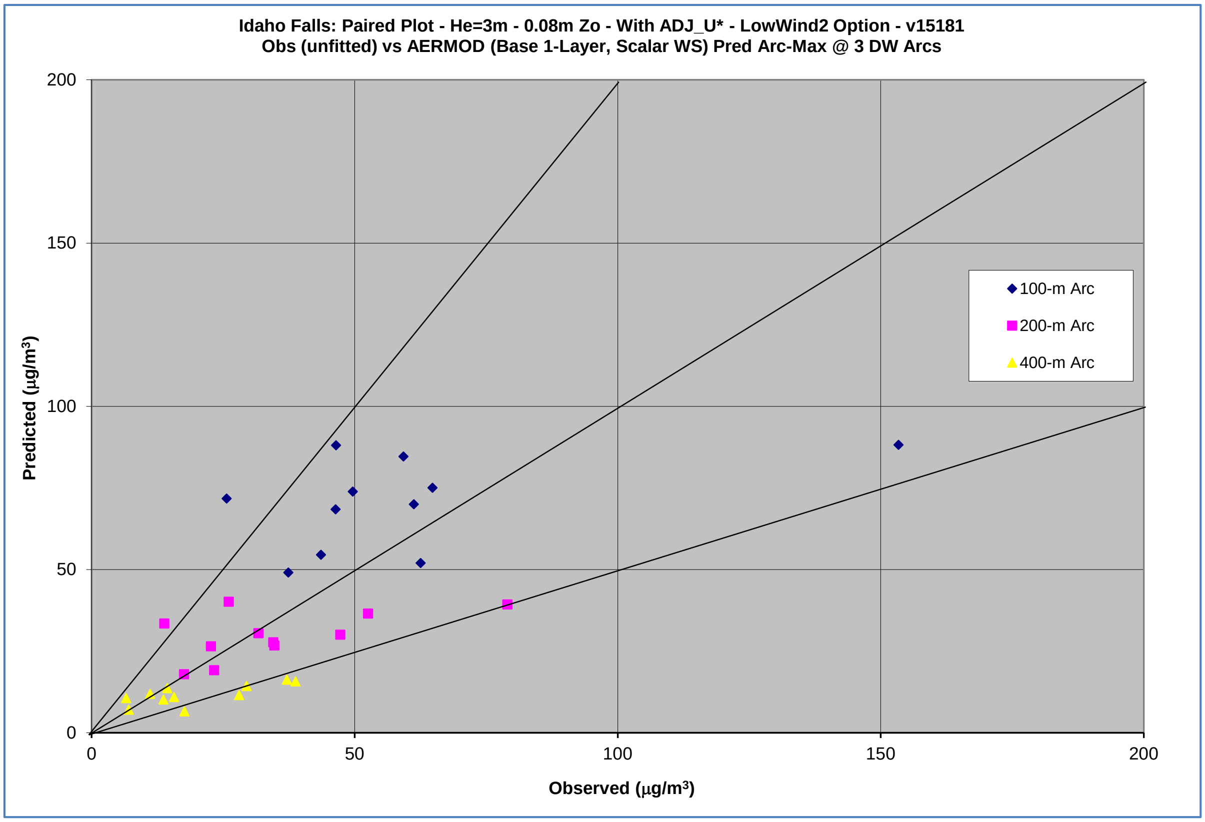
Idaho Falls: Resid Plot vs. DW Dist - He=3m - 0.08m Zo - With ADJ_U* - NoLW Option - v15181
Pred (AERMOD Degraded 1-Layer, Scalar WS) vs Obs (unfitted)
100.00
10.00
1.00
0.10
0.01
Predicted / Observed
100 - ns=11
200 - ns=11
400 - ns=11
Receptor Arcs

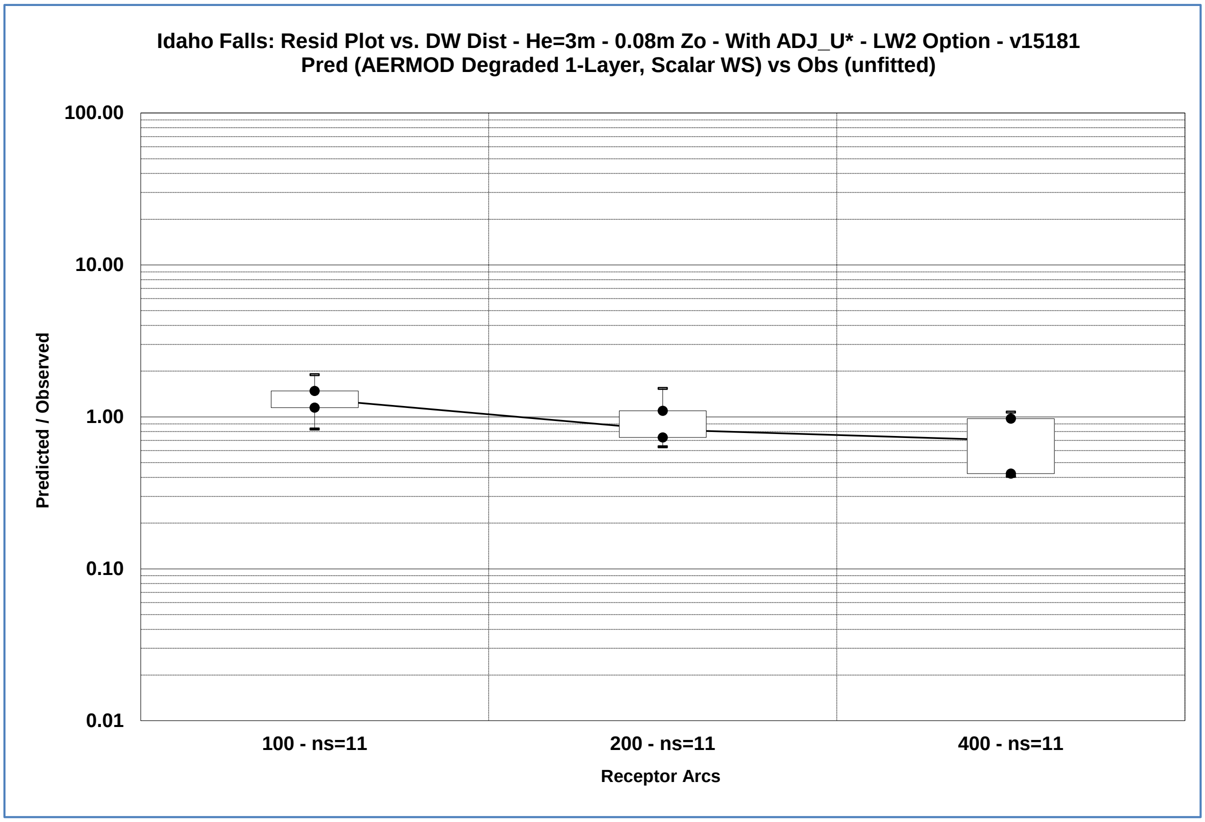

Idaho Falls: Q-Q Plot - He=3m - 0.08m Zo - With ADJ_U* - LowWind1 Option - v15181
Obs (unfitted) vs AERMOD (Degraded 1-Layer, Scalar WS) Predicted Arc-Max @ 3 DW Arcs
Predicted (µg/m³)
Observed (µg/m³)
100-m Arc
200-m Arc
400-m Arc
0
50
100
150
200

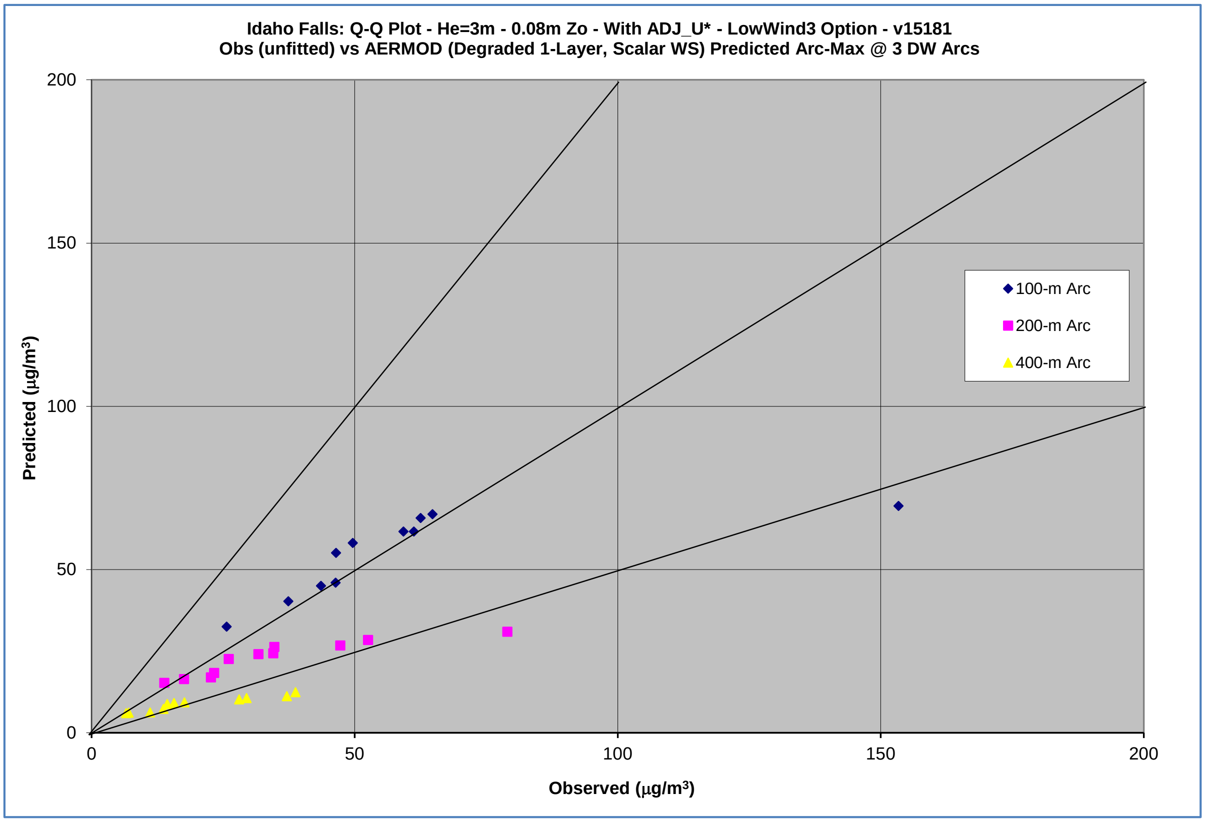

Idaho Falls: Paired Plot - He=3m - 0.08m Zo - With ADJ_U* - LowWind1 Option - v15181
Obs (unfitted) vs AERMOD (Degraded 1-Layer, Scalar WS) Pred Arc-Max @ 3 DW Arcs
Predicted (µg/m³)
Observed (µg/m³)
100-m Arc
200-m Arc
400-m Arc
0
50
100
150
200

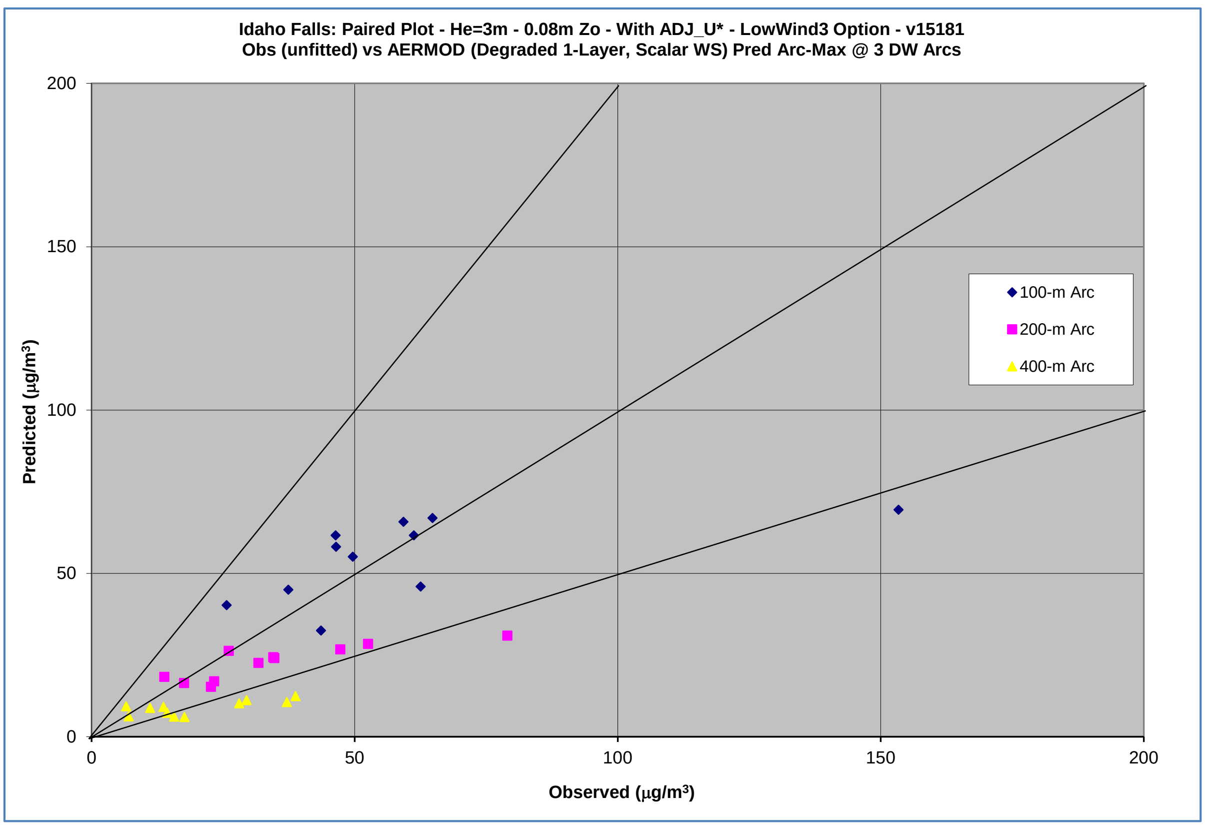

Idaho Falls: Resid Plot vs. DW Dist - He=3m - 0.08m Zo - With ADJ_U* - LW1 Option - v15181
Pred (AERMOD Degraded 1-Layer, Scalar WS) vs Obs (unfitted)
100.00
10.00
1.00
0.10
0.01
Predicted / Observed
100 - ns=11
200 - ns=11
400 - ns=11
Receptor Arcs

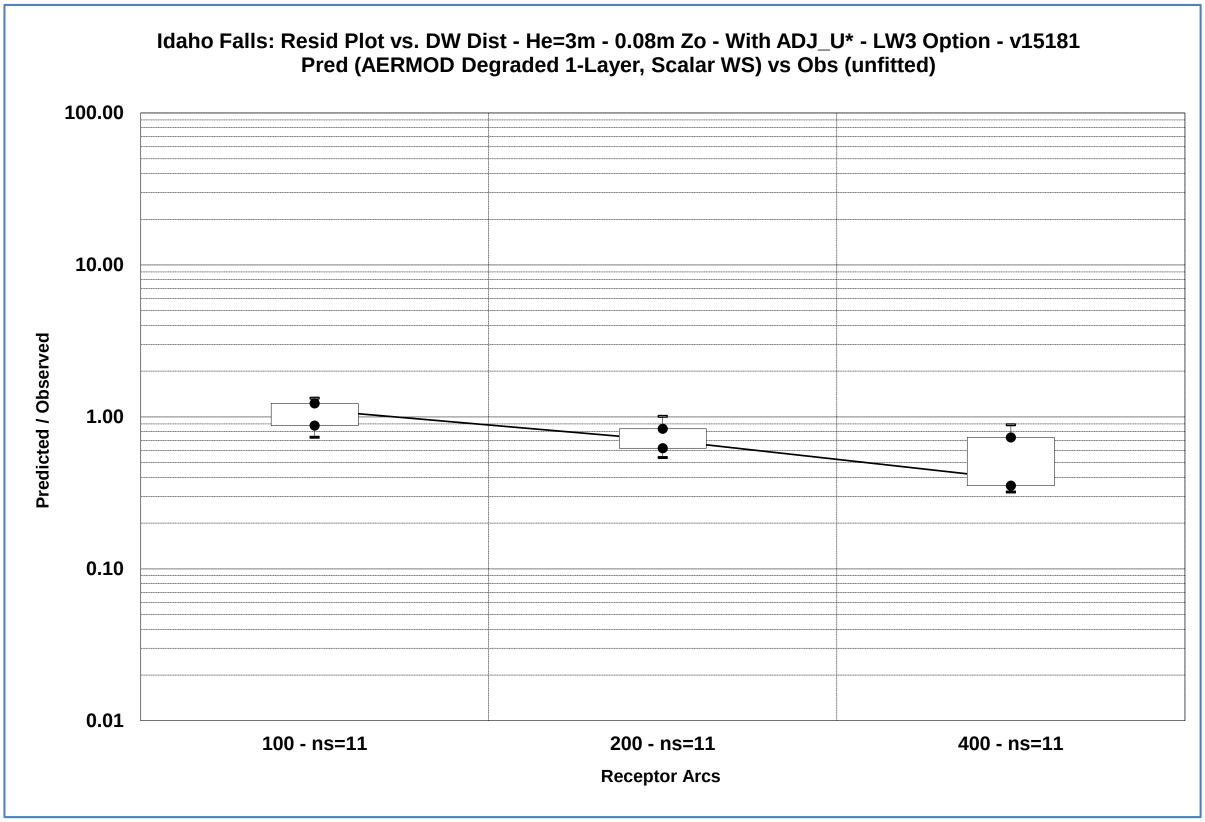

Idaho Falls: Q-Q Plot - He=3m - 0.08m Zo - With ADJ_U* - LowWind2 Option - v15181
Obs (unfitted) vs AERMOD (Degraded 1-Layer, Scalar WS) Predicted Arc-Max @ 3 DW Arcs
Predicted (µg/m³)
Observed (µg/m³)
100-m Arc
200-m Arc
400-m Arc
0
50
100
150
200


Idaho Falls: Paired Plot - He=3m - 0.08m Zo - With ADJ_U* - LowWind2 Option - v15181
Obs (unfitted) vs AERMOD (Base 1-Layer, Scalar WS) Pred Arc-Max @ 3 DW Arcs
Predicted (µg/m³)
Observed (µg/m³)
100-m Arc
200-m Arc
400-m Arc
0
50
100
150
200


Idaho Falls: Resid Plot vs. DW Dist - He=3m - 0.08m Zo - With ADJ_U* - LW2 Option - v15181
Pred (AERMOD Degraded 1-Layer, Scalar WS) vs Obs (unfitted)
100.00
10.00
1.00
0.10
0.01
Predicted / Observed
100 - ns=11
200 - ns=11
400 - ns=11
Receptor Arcs


Idaho Falls: Q-Q Plot - He=3m - 0.08m Zo - With ADJ_U* - LowWind3 Option - v15181
Obs (unfitted) vs AERMOD (Degraded 1-Layer, Scalar WS) Predicted Arc-Max @ 3 DW Arcs
Predicted (µg/m³)
Observed (µg/m³)
100-m Arc
200-m Arc
400-m Arc
0
50
100
150
200


Idaho Falls: Paired Plot - He=3m - 0.08m Zo - With ADJ_U* - LowWind3 Option - v15181
Obs (unfitted) vs AERMOD (Degraded 1-Layer, Scalar WS) Pred Arc-Max @ 3 DW Arcs
Predicted (µg/m³)
Observed (µg/m³)
100-m Arc
200-m Arc
400-m Arc
0
50
100
150
200


Idaho Falls: Resid Plot vs. DW Dist - He=3m - 0.08m Zo - With ADJ_U* - LW3 Option - v15181
Pred (AERMOD Degraded 1-Layer, Scalar WS) vs Obs (unfitted)
100.00
10.00
1.00
0.10
0.01
Predicted / Observed
100 - ns=11
200 - ns=11
400 - ns=11
Receptor Arcs

The Lovett data base includes a single 145m stack located within a few kilometers of complex terrain. The site area is shown below:

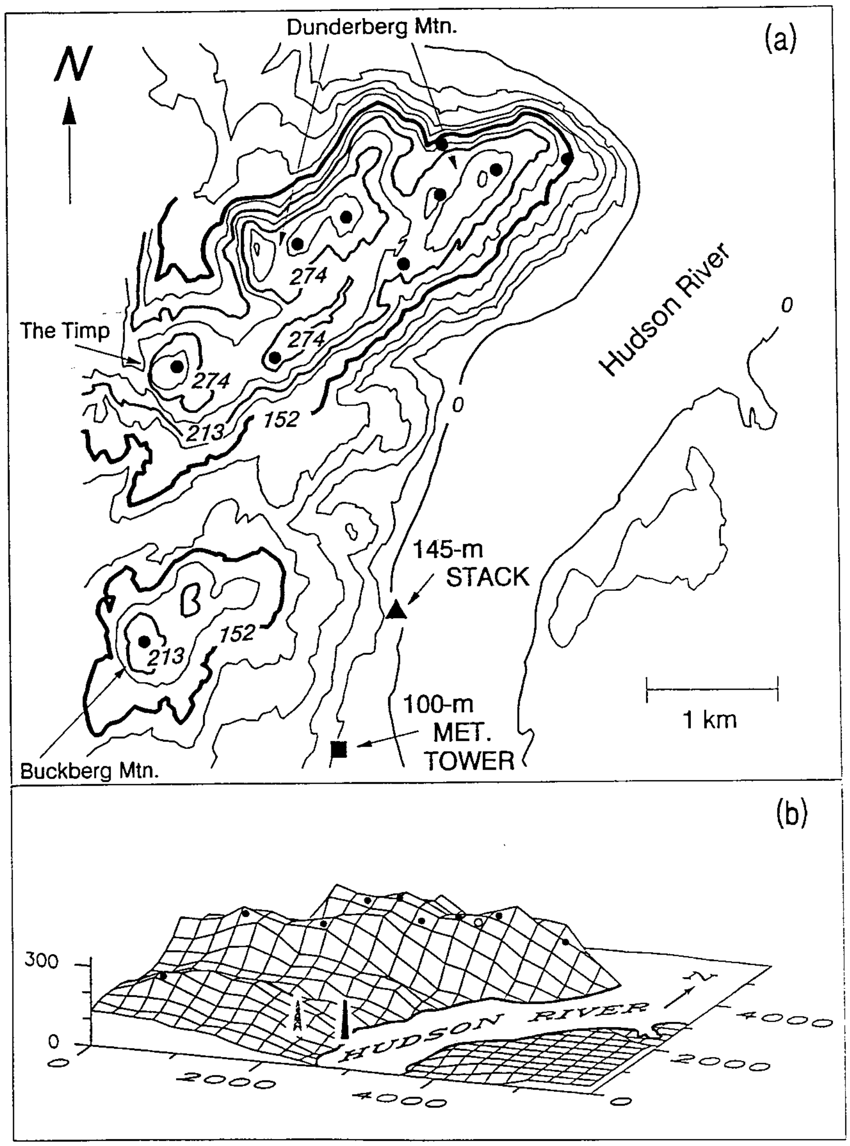
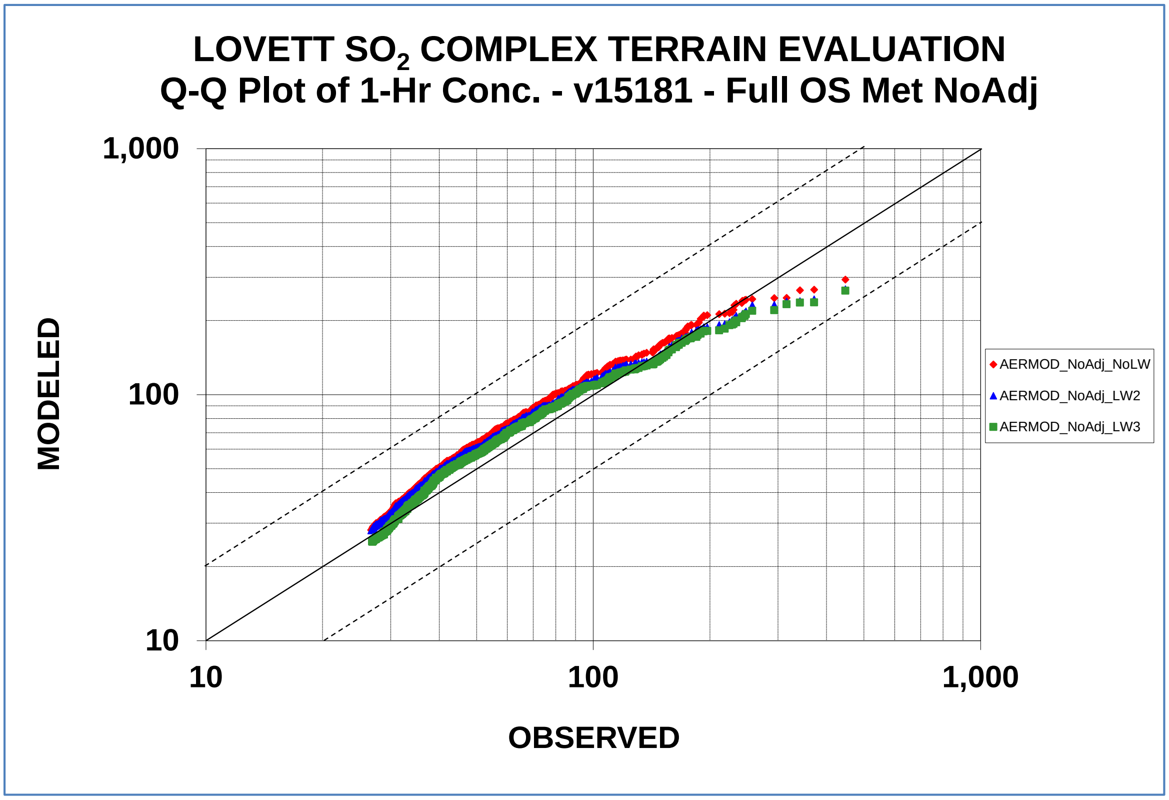
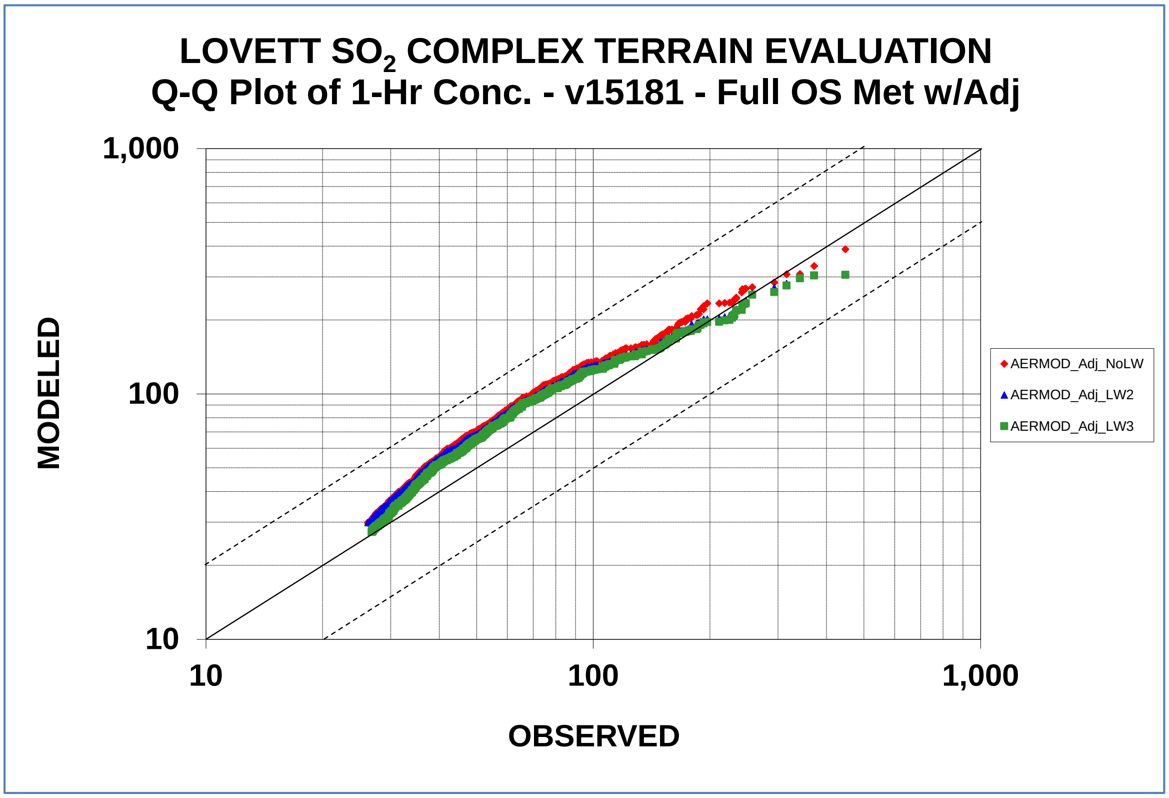


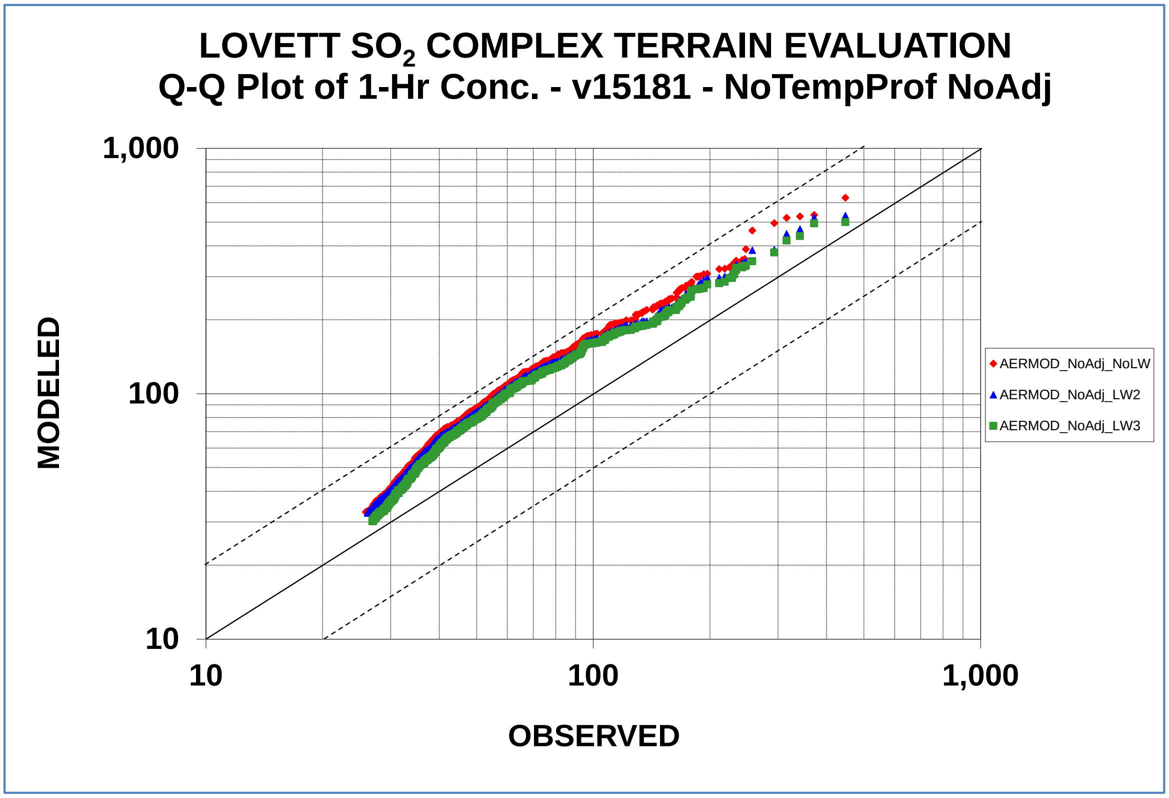
Figure 7 **Depiction of the Monitoring Network Used for the Lovett Complex Terrain Model Evaluation Study**

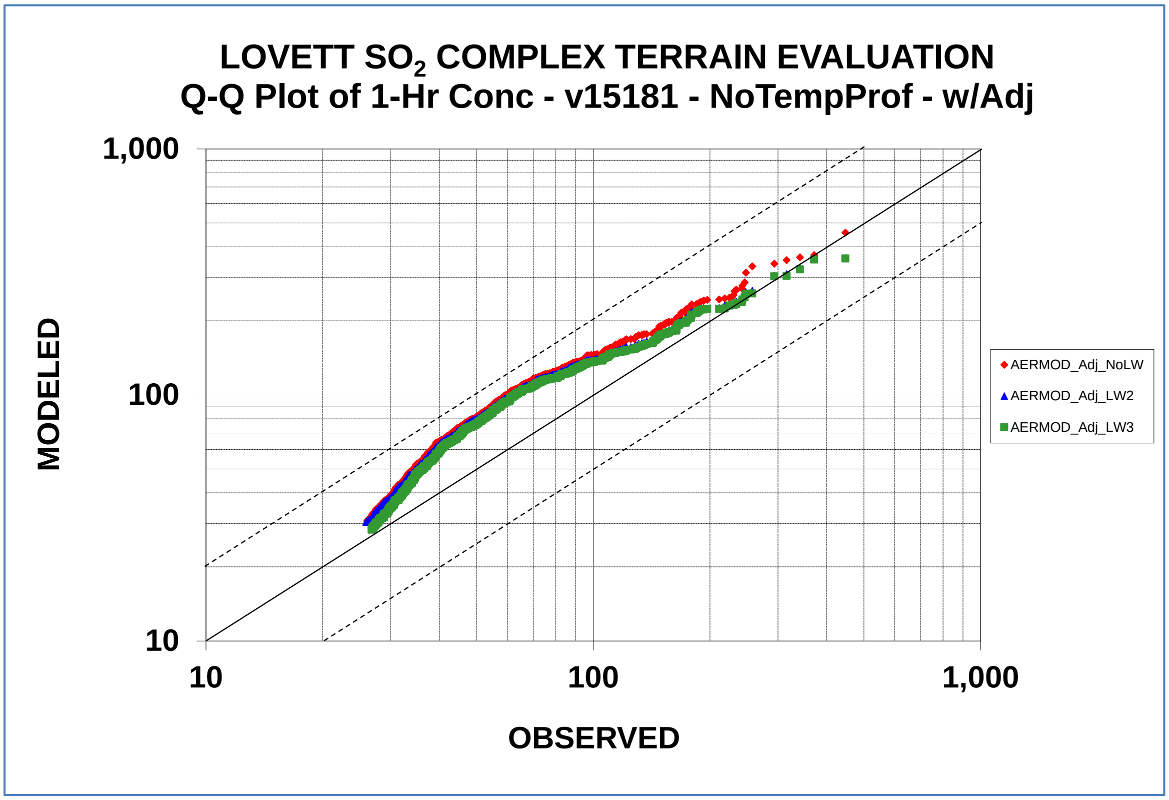
The Lovett data base includes a 100m meteorological tower with wind speed, wind direction, sigma-theta and temperature collected at the 10m, 50m, and 100m levels. In addition, sigma-w was also collected at the 10m and 100m levels. Past evaluations of AERMOD have shown good performance. Updated 1-hour results are presented below comparing model performance with full onsite meteorological data with and without the ADJ_U* and LowWind options, followed by comparisons with and without the ADJ_U* and LowWind options using degraded meteorological data inputs. Including the ADJ_U* option with full onsite meteorological data shows a slight improvement in model performance without the LowWind options, and little difference in performance for the LowWind2 compared to LowWind3 (the LowWind1 option was not included in this study.

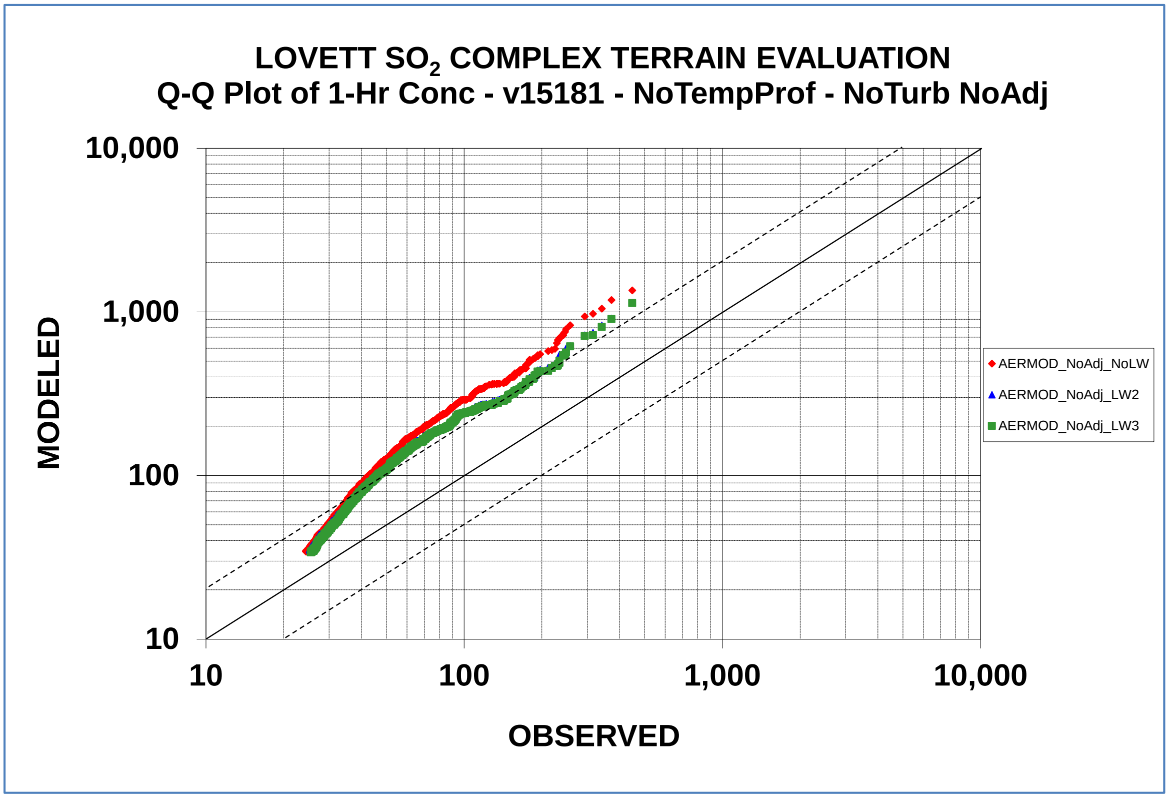
The next set of comparisons are based on no temperature profile in the Lovett site-specific meteorological data. The model shows some overprediction without the temperature profile and without the ADJ_U* option, especially without the LowWind options. The model overprediction without the temperature profile is noticeably reduced when the ADJ_U* option is used. The modeled results shows more significant overprediction when the meteorological data is further degraded by eliminating the turbulence data (i.e., sigma-theta and sigma-w), with the overprediction bias exceeding a factor of 2. The overprediction without the temperature profile and turbulence data is significantly reduced when the ADJ_U* and LowWind options are used. It’s also worth noting that results for the LowWind2 (LW2) and LowWind3 (LW3) options are nearly indistinguishable in this case.

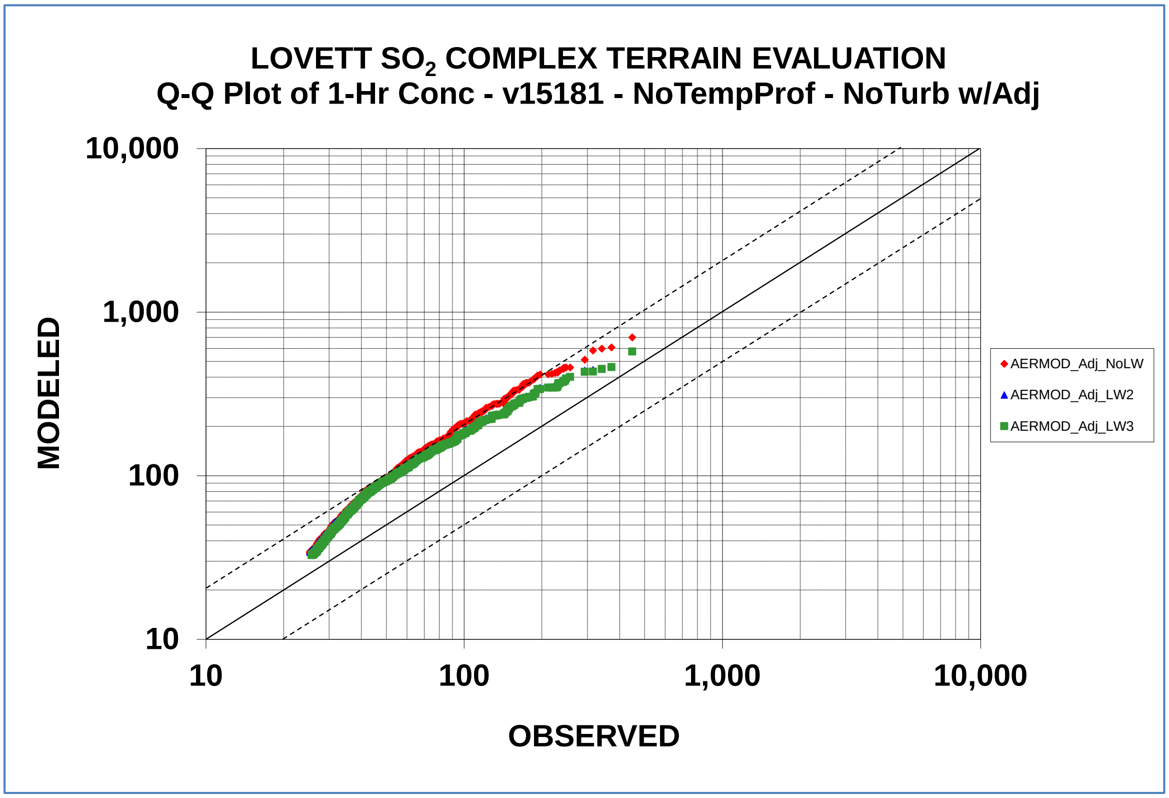

LOVETT SO2 COMPLEX TERRAIN EVALUATION
Q-Q Plot of 1-Hr Conc. - v15181 - Full OS Met NoAdj
MODELED
1,000
100
10
10
100
1,000
OBSERVED
AERMOD_NoAdj_NoLW
AERMOD_NoAdj_LW2
AERMOD_NoAdj_LW3


LOVETT SO2 COMPLEX TERRAIN EVALUATION
Q-Q Plot of 1-Hr Conc. - v15181 - Full OS Met w/Adj
MODELED
1,000
100
10
10
100
1,000
OBSERVED
AERMOD_Adj_NoLW
AERMOD_Adj_LW2
AERMOD_Adj_LW3


LOVETT SO_2 COMPLEX TERRAIN EVALUATION
Q-Q Plot of 1-Hr Conc. - v15181 - NoTempProf NoAdj
MODELED
OBSERVED
1,000
100
10
10
100
1,000
AERMOD_NoAdj_NoLW
AERMOD_NoAdj_LW2
AERMOD_NoAdj_LW3


LOVETT SO_2 COMPLEX TERRAIN EVALUATION
Q-Q Plot of 1-Hr Conc - v15181 - NoTempProf - w/Adj
MODELED
OBSERVED
1,000
100
10
10
100
1,000
AERMOD_Adj_NoLW
AERMOD_Adj_LW2
AERMOD_Adj_LW3


LOVETT SO_2 COMPLEX TERRAIN EVALUATION
Q-Q Plot of 1-Hr Conc - v15181 - NoTempProf - NoTurb NoAdj
MODELED
OBSERVED
10,000
1,000
100
10
AERMOD_NoAdj_NoLW
AERMOD_NoAdj_LW2
AERMOD_NoAdj_LW3


LOVETT SO_2 COMPLEX TERRAIN EVALUATION
Q-Q Plot of 1-Hr Conc - v15181 - NoTempProf - NoTurb w/Adj
MODELED
OBSERVED
10,000
1,000
100
10
AERMOD_Adj_NoLW
AERMOD_Adj_LW2
AERMOD_Adj_LW3

Proposed Updates to AERMOD Modeling System

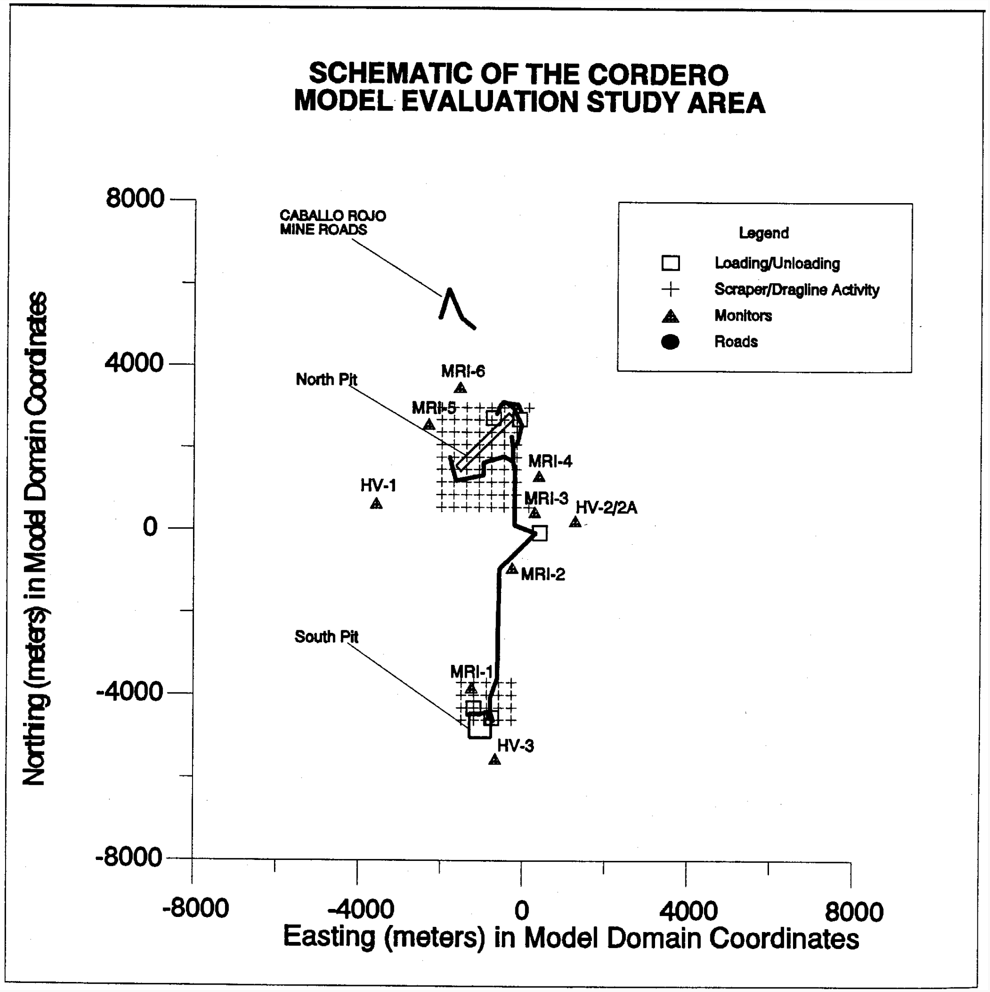
Roger W. Brode
U.S. EPA/OAQPS/AQAD/AQMG

11th Modeling Conference
Research Triangle Park, NC
August 12, 2015

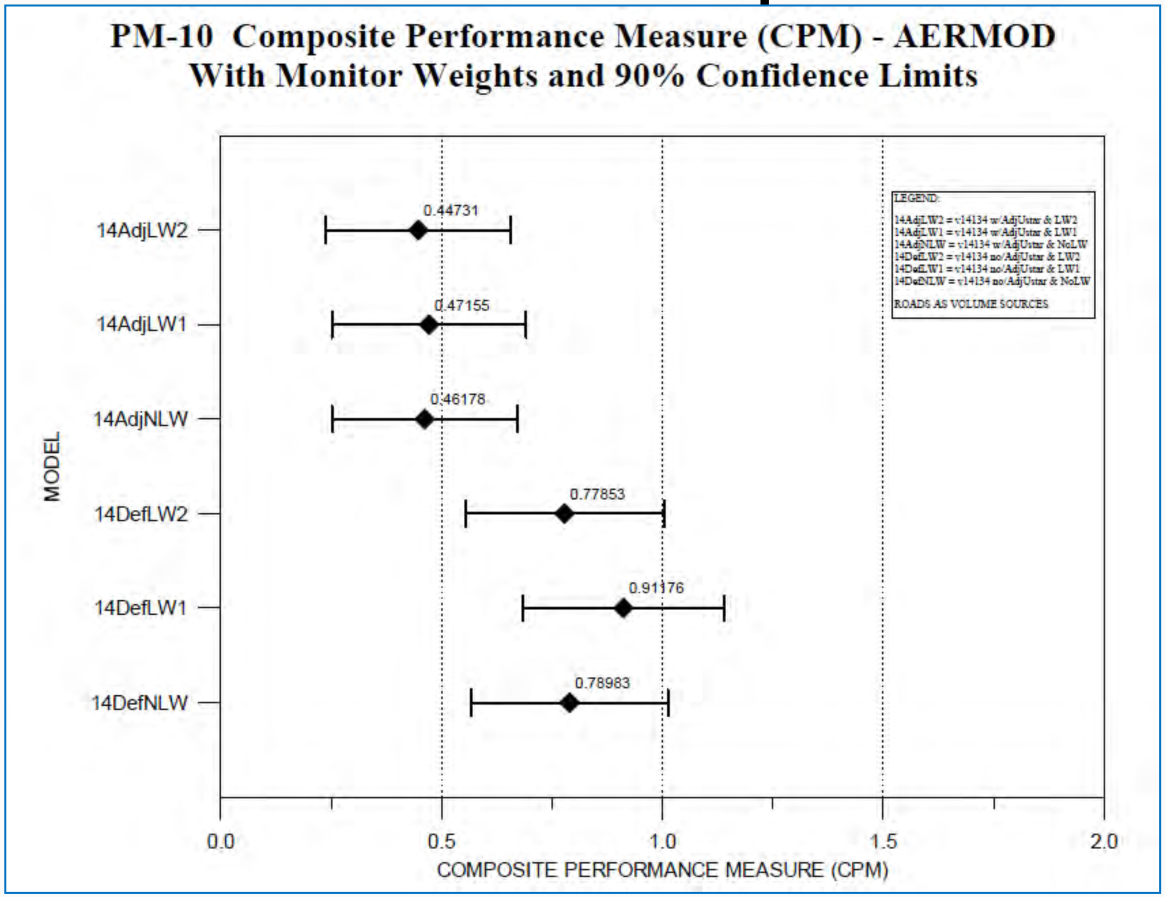
Evaluation of Beta Options

- Surface Coal Mine PM10 Study
  - Cordero Rojo Mine in eastern Wyoming
  - Two-month Field Study in 1993 to evaluate new emission factor and dispersion model options
  - Evaluated 24-hour averages for PM-10 and TSP
  - Majority of emissions (~75%) from roadways
  - Cox-Tikvart protocol for determining the “best performing” model applied to give “confidence intervals” on model performance
- Results presented are for ADJ_U* and LW1 and LW2 based on v14134, but are likely to be similar for v15181

Evaluation of Beta Options

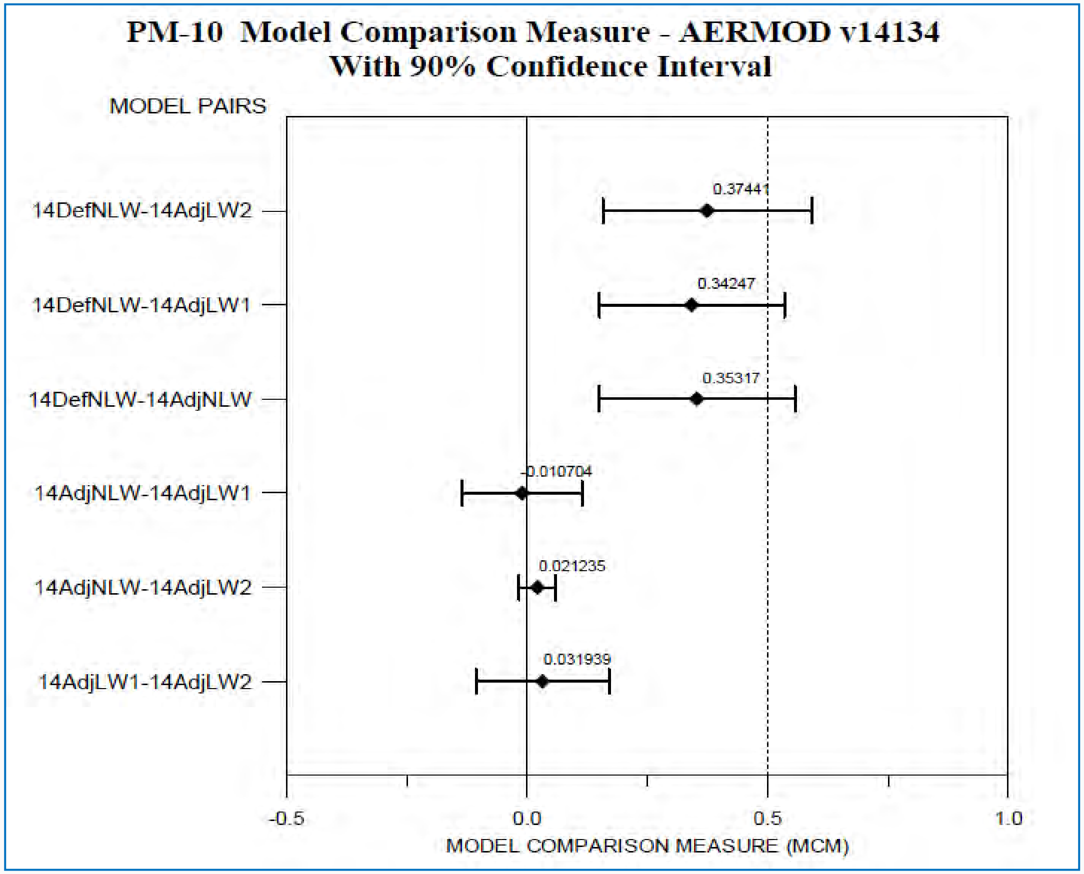


Evaluation of Beta Options – CPM



Note: Smaller value of CPM indicates "better" performance

Evaluation of Beta Options - MCM



Note: If MCM confidence interval spans zero performance differences not statistically significant

Summary of Cordero PM10 Evaluation

- Use of the proposed ADJ_U* option in AERMET appears to significantly improve model performance for this study;
  - The confidence intervals for the Model Comparison Measure (MCM) do not cross zero when comparing results with ADJ_U* vs. no ADJ_U*;
  - The LW1 and LW2 options in AERMOD appear to have limited affect on modeled performance.